1947

Effect of freezing on tenderness and on ice crystal formation in poultry after various periods of aging

Mary Agnes Frances Carlin
Iowa State College

NOTE TO USERS

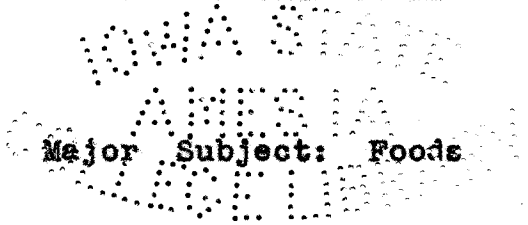
EFFECT OF FREEZING ON TENDERNESS AND ON ICE CRYSTAL FORMATION IN POULTRY AFTER VARIOUS PERIODS OF AGING

by

Mary Agnes Frances Carlin

A Thesis Submitted to the Graduate Faculty
for the Degree of

DOCTOR OF PHILOSOPHY



Major Subject: Foods

Approved:

Signature was redacted for privacy.

In Charge of Major Work

Signature was redacted for privacy.

Head of Major Department

Signature was redacted for privacy.

Dean of Graduate College

Iowa State College

1947

TABLE OF CONTENTS

Page

INTRODUCTION

The desirable qualities in cooked poultry are tenderness, juiciness, good aroma and flavor. To be acceptable, frozen poultry should retain these characteristics to as high a degree as possible. The primary value of freezing poultry is the maintenance of existing quality; hence the handling of poultry before freezing should maintain maximum quality.

Studies by Hanson (1941), Stewart, Lowe, Harrison and McKeegan (1945) and Lowe et al. (1946) have contributed to the knowledge of post-mortem changes in broilers, roasters and fowl and have indicated desirable practices in handling poultry to obtain maximum quality before cooking and freezing. Stewart, Hanson, Lowe and Austin (1945) showed that freezing at -90°, -50°, and -5°F. did not produce detectable differences in palatability scores of broilers held two and 18 hours before freezing. Wills (1946) found fryers eviscerated and frozen within three hours after killing were less tender than similar fryers held 24 to 48 hours. DuBois, Tressler and Fenton (1942) indicated that various freezing rates plus storage at -8°F. produced no differences in palatability.

The changes that take place during the freezing process alone have not been studied. Such questions as the following need to be studied: does freezing tenderize chicken? what

changes occur in the connective tissues and muscle fibers of roasters and fowl during aging and subsequent freezing?

This investigation was undertaken to determine the effect of freezing per se on roasters and fowl. The effects of five periods of aging before freezing at 0° and -30°F. on the histological and palatability factors were studied.

The specific objectives of this study were as follows:

1. To determine the effects of the length of aging plus the rate of freezing and thawing on the palatability of roasters and fowl.
2. To determine the histological changes which occur in muscle tissues of roasters and fowl during aging and freezing.
3. To correlate any histological changes with changes in palatability, especially in tenderness and "dryness."
4. To compare the effects of the rate of freezing on the distribution of ice crystals in the muscle fibers of frozen poultry.

Birds were cut in half, and one half was used as a control. This eliminated the variation between birds. Hence measurements and conclusions were based on halves of birds. The rate of freezing was recorded by a Leeds and Northrup Micromax temperature recorder (using copper-constantan thermocouples). The subjective tests included scores of four judges on aroma, flavor, tenderness and juiciness of the cooked chicken. Objective measurements included the use of the shear machine as an indication of tenderness of the pectoralis major muscle and histological studies on the raw, frozen and cooked pectoralis major muscle of the breast of chicken.

REVIEW OF LITERATURE

Structure of Muscle

The nature and action of muscle are problems that have been studied from many different angles. Probably the structure of the muscle cell has been approached from so many different points of view because of its unusual appearance under the microscope and the changes caused by contraction and rigor. Striated muscle, according to Maximow and Bloom (1944), consists of many long cylindrical fibers which are bound together and surrounded by connective tissue. Each fiber is an elongated, multi-nucleated cell composed of sarcoplasm, fibrils and nuclei which are surrounded by a cell membrane, the sarcolemma.

The individual muscle fibers vary in length from 1 to 41 millimeters and from 10 to 100 microns in diameter (Maximow and Bloom, 1944). In small muscles, the fibers may continue the length of the muscle. In larger muscles, the fibers are shorter than the muscle, one end may be connected to the tendon and the other end terminate among the other fibers, or both ends may be free in the muscle. The thickness of the fiber varies with the animal and the muscle as well as with the age of the animal and the amount of exercise.

The parallel muscle fibers are held together by

connective tissue composed of irregularly arranged collagenous, reticular and elastic fibers, and many varieties of connective tissue cells including fat cells. The amount of elastic fibers in the connective tissue varies with the type of muscle.

The myofibrils, which run lengthwise in the muscle cell, appear as long parallel threads composed of alternating light and dark portions. Bremer (1944) states:

> The most conspicuous characteristic of skeletal muscle, which has caused it to be called striated, is the marking with alternating light and dark bands, seen only in longitudinal section. The myofibrils are composed of alternating light and dark portions, and are so arranged that the dark parts of one fibril are beside the dark parts of adjacent fibrils. As a result of the close crowding of the fibrils, alternating light and dark transverse bands appear to pass from one side of the fiber to the other, and these are the striations. When seen obliquely, the dark and the light areas become superposed and confused, and the longitudinal myofibrils become conspicuous.

The fact that the appearance of the striated muscle fiber depends on whether it is contracted, passively stretched or relaxed and also on the focus of the microscope probably accounts for the great amount of controversy in the literature on the position of the bands and their relative size.

In working on fixed frog muscle, Carey (1940) found that the cross striae are multiplied with increase in temperature. He believed that the fine striations which occurred in the contraction nodes came from active multiplication of the striae by splitting.

In 1942 Carey reported further evidence using the living muscle of the fresh-water shrimp. He observed a complete reversibility of the increase in number of cross-striations with temperature. He concluded that "the sarcomere as a constant unit is a morphologic myth." He believed the cross-striation to be the expression of the functional state of the fibers, comparable to bands of inorganic precipitates in gelatin-filled micro-capillaries, a model in which the spacing of the bands depends on chemical concentrations, heat and light influences. On the other hand, Speidel and Jordan (1942) were convinced from their own experimental experience with various striated muscles, which included those of shrimps, that the number of sarcomeres remained constant. They feel that an examination of Carey's photomicrographs does not reveal inconsistency of the sarcomeres, and that Carey was misled by telophragmatic doubling or tripling of the dark striae of the A-disc.

The exact nature of the finer structure of the myofibrils is still controversial. The most recent theory has been advanced by Szent-Gyorgyi (1945,1946), who has developed a molecular theory of muscle structure and claims that cross-striations are non-existant. He believes that the fibril is composed of a combination of actin and myosin, called actomyosin, and that these two proteins are so combined that one forms a long rod or thread while the other is wound

around it in a spiral.

That the dark and light discs are more than mere optical illusions is evidenced by the fact that they react differently to stains. These bands are so conspicuous that it is not surprising that many attempts have been made to explain their genesis. For the purpose of this study the existence of bands or discs as described by Maximow and Bloom (1944) is used, as this theory seems to be the most generally accepted. One band is definitely refractile and appears dark and shining; it stains intensely with iron hematoxylin and since it is anisotropic, or doubly refractile, it is designated A disc (also Q). The light band is called the J or I band, is isotropic and with the usual stains remains colorless. The A and I discs are approximately the same height in the resting fibrils. If the fibers are passively stretched, the I disc appears taller.

Proteins of Muscle

The protoplasm in the muscle fiber is an aqueous mixture containing protein, fat, glycogen, pigments and other organic and inorganic compounds. Moran and Smith (1929) state the semi-liquid consistency of muscle is caused by the presence of proteins in the colloidal state. The proteins form the bulk of the muscle substance and are characterized by a great sensitivity to changes in the concentration of

salts and acids which are present in the muscle or which may be formed as a result of activity or the changes brought about by death.

The proteins of muscle can be separated into two main groups, the intracellular and the extracellular proteins. The extracellular proteins consist principally of collagen and elastin. The intracellular proteins are composed of a mixture of proteins which are separated on the basis of their solubility in water and salt solutions.

One of the most recent contributions on muscle proteins has been made by Szent-Gyorgyi and his associates (1946). In their studies on the purification and interaction of muscle proteins, the principal protein, myosin, was isolated in the crystalline form as a potassium complex from solutions containing a low concentration of potassium chloride. Crystalline myosin is soluble in water and has a strong double refraction of flow, which is due to association of myosin particles since it is abolished by salt. They describe another protein, actin, a hydrophilic colloid capable of existing in globular as well as in the fibrous form. Actin solutions have a low viscosity and do not show double refraction of flow. However, when dilute solutions of myosin and fibrous actin are mixed, a viscous substance, fibrous actomyosin, is formed whose properties vary with the proportions of the components. The most striking property of

fibrous actomyosin is its contraction and dehydration in the presence of adenosinetriphosphate. A molecular theory of muscle contraction has been developed based on the properties of myosin and actin and their interactions with adenosinetriphosphates and inorganic ions.

The properties of proteins are closely related to their structure. Recently there has been considerable work done on the structure of protein using x-ray diffraction patterns in an attempt to explain the structure and behavior of muscle. Astbury offers the hypothesis that the contraction of muscle is due to the supercontraction of its myosin, and claims that x-ray pictures of both living and dead muscle substantiate this. Astbury and co-workers (1934,1940) reported x-ray studies of myosin show that the micelles consist of long chains of amino acids arranged parallel to one another, being held together by cross linkages between reactive R groups, hydrogen bonds, and van der Waals' forces. The chains thus formed may be considered to be folded in such a way that under stress they can be either stretched or increasingly folded.

Relation between muscle structure and tenderness of meat

Each of the three constituents of muscle, the fat, the connective tissue and the muscle fibers, will contribute to the tenderness or toughness of meat. The collagen and

elastin of connective tissue are affected differently by aging and cooking. The amount and distribution of connective tissue varies with the animal, also with the age and sex of the animal and with different muscles. A few studies have been made on the actual amount of connective tissue in the muscles of animals of different ages. Mitchell, Zimmermann and Hamilton (1927) found that age does not greatly influence the connective tissue in muscle and that foreshank, chuck ribs and navel of beef had the highest per cent of collagen. Mackintosh, Hall and Vail (1936) reported that the collagen nitrogen was higher in mature than in yearling beef, and as the collagen nitrogen rose, the shear increased and the tenderness score decreased.

According to Lehman (1907) measurements on the mechanical strength of muscle showed it to be directly proportional to the amount of connective tissue present. He states that the muscles that are most active and, therefore, subject to the greatest strains have the largest amount of connective tissue and are the least tender. Ramsbottom, Strandine and Koonz (1945), in studying 25 different major muscles of beef, found that tenderness varied from muscle to muscle with a few instances of variation within the muscle. They state: "Although abundant connective tissue tended to increase the shear readings of muscles, there appear to be other important factors affecting tenderness." Harrison (1947)

reported similar results on five muscles of beef.

The data of Ramsbottom, Strandine and Koonz (1945) showed that there was no relationship between the amount of fat within the muscle and the shear of the raw or cooked muscle; however, they felt that differences in the amount of connective tissue associated with the intramuscular fat might explain why there was not a positive relationship between high fat content of muscles and low shear values. Stewart, Lowe, Harrison and McKeegan (1945) found that the adductor longus thigh muscle of chicken (one of the five muscles studied), which has large amounts of connective tissue well interspersed with fat, was the toughest muscle and showed little increase in tenderness throughout the five-day aging period.

There is some evidence which suggests that the connective tissue is not the sole anatomical factor determining tenderness. Hammond (1940) has shown, according to histological measurements on young lamb, that the proportion of connective tissue to muscle-substance is higher in the mature animal, yet the muscle of the young animal is more tender. He is of the opinion that tenderness is related to the size of the muscle bundle or "grain of the meat." However, since fetal lamb was used as the young animal, the differences in tenderness might be explained by the difference in texture between embryonic and mature connective tissue. Moran and Smith (1929) investigated the relationship between the size of the

fibers, the number of fibers to a bundle and the tenderness of the muscle. In the process of development, an increase in the size of the fiber is accompanied by an increase in the strength and amount of connective tissue and also in the size of the muscle bundle. They concluded that in the adult animal the size of the bundle is necessarily a function of the connective tissue content and that a more credible theory would be to consider the connective tissue content the chief determining factor in tenderness. Brady (1937) reported the smaller the fibers, the finer the texture and the more tender the beef.

There has been no published comparable work on the correlation between the amount of connective tissue, the amount of fat or size of fibers and tenderness in poultry. Studies made on the optimum time of storage of poultry by Lowe (1939), Hanson, Stewart and Lowe (1942) and Stewart, Lowe, Harrison and McKeegan (1945) have shown that breast muscle is more tender than thigh muscle and also that younger birds, broilers and roasters, are more tender than fowl. Lowe, who has made a very thorough histological study of poultry, has observed, in a report on fowl, that there was a larger amount of connective tissue between the fibers of fowl than between the fibers of broilers, which may contribute to the toughness of fowl (Stewart, Lowe, Harrison and McKeegan, 1945).

Post-mortem Changes in Muscle

After death, the changes which occur in the muscles of animals are brought about by enzymes, micro-organisms and by chemical and physical means that alter the structure and the chemical composition of the tissue. Parnas (1933) states that:

> . . . all the familiar metabolic changes (viz., lactic acid formation, deamination, splitting-off of phosphorus from phosphocreatine and adenosine triphosphoric acid) are known to occur at a very fast rate in the traumatic and postmortal decompositions. . .

Rigor

Grossly one may observe that the muscle which was soft and pliant becomes stiff or rigid, a condition known as rigor mortis, and after some time the rigor passes and the muscle becomes pliant again. Moran and Smith (1929 described the changes occurring during rigor of normal intact muscle as

> 1) Hardening and stiffening; 2) shortening; 3) loss of elasticity; 4) loss of transparency; 5) loss of power to contract when electrically stimulated; 6) formation of lactic acid; and 7) production of heat (heat of rigor).

Experimentally the forms of rigor produced may vary with the methods used to kill the tissues, such as heat, freezing, sudden electrical shock, injection of toxin, or exposure to volatile anesthetics. Also the time of the

beginning of rigor appears to vary with 1) the species of animal, 2) the age of the animal, 3) different animals of the same species, 4) different muscles of the same animal, 5) the extent of acidity in the muscle, 6) the nutritive state of the animal, and 7) the amount of physical activity just prior to killing. Smith observed that an animal which struggled violently both before and after stunning went into rigor sooner than a quiet animal (1939).

Hanson (1941) reports that:

> It was found that the development of rigor varied widely in the same bird. In one bird rigor had passed from the muscle after 1 hour and 40 minutes storage (or had never developed), whereas other birds were still in rigor after 15 hours of storage.

Chemical and physical changes during the onset of rigor

The chemical changes which accompany rigor in the normal animal are an increase of lactic acid, paralleled by a drop in pH, a decrease in glycogen and hydrolysis of nearly all the esterified phosphates to orthophosphates. Some investigators, including Mirsky (1935), have found that as much as 70 per cent of the myosin of muscle became insoluble in neutral salt solutions during rigor, but Smith (1937) was unable to confirm this loss of solubility unless the temperature of storage was high enough to produce heat denaturation.

Callow (1935) followed the changes in muscle after death by measurement of the electrical resistance. He found

that the electrical resistance of muscle tissue is relatively high after death, but is reduced to one-half or one-third of the initial value when meat is ready for curing (approximately 48 hours). The resistance across and parallel to the fibers became the same. Callow explained this change from high to low resistance by a change in the muscle structure from a closed to an open structure. This open structure fits in with the histological picture described by Hanson (1941). Callow also found a correlation between pH and electrical resistance; that is, low electrical resistance was associated with low values for pH and vice versa.

Histological changes during rigor

The microscopic studies of the muscle fibers in rigor reveal that there is a variable response of the fibers. Some fibers develop a wavy or kinked appearance which is interpreted by Carey (1940) as indicating that these fibers are passively retracted by the contraction of the noded fibers and that they are not under tension. Other fibers exhibit rigor nodes which have characteristic zones of contraction and rarefaction. The appearance of the fibers varies with the means used to induce rigor. When rigor was produced by extreme heat, freezing and electrical stimulation, the fibers showed irregular transverse bands of dense material

having very fine striations, alternating with rarefied areas having widely separated striations. Carey (1940) has published excellent histological studies on striated muscle in frogs. He studied the heat rigor nodes produced in muscle by exposure to temperatures of 20 to 40°C. He described the characteristics of the nodes and internodes as follows:

> The pressure nodes of the striated fiber contraction waves have deep differential chemical staining, wide diameter, condensed cytoplasm and rounded, compressed nuclei, multiplication of fine striae and an increase of anisotropy and mineral ash content. The tension internodes stain relatively less deeply and have narrow diameter, rarefied fibrillated cytoplasm, greatly elongated nuclei, coarse striae and a decrease of anisotrophy and mineral ash content. . . . The numbers of light and dark cross striae appear to be related to an optimum range of temperature and rate of chemical reaction.

Hanson (1941), working with broilers, confirmed Carey's work on the microscopic structure of skeletal muscle in heat rigor. The excellent photomicrographs, similar to those of Carey, are shown in a paper by Hanson, Stewart and Lowe (1942). Paul (1943) also found a similar microscopic appearance in beef muscle.

Aging

The term "aging" or "ripening" generally refers to the practice of holding meat at temperatures of 34 to 36°F. for the purpose of improving the quality, particularly the tenderness, of the meat. The length of time required for ripening varies with the animal type, the degree of ripened

flavor desired and the temperature of storage. Noticeable changes are: altered flavor, increase in the ease with which juice may be pressed from the meat and increase in tenderness; the last two are probably correlated with histological changes shown by disappearance of cross striae.

Organoleptic changes with aging

A number of studies on the quality of ripened meat have been reported over a period of years. The investigators seem agreed that an aging period of from seven to 15 days is necessary for the greatest improvement in tenderness in meat [Moran and Smith (1929), Tressler and Murray (1932), Hiner and Hankins (1941), Paul (1943) and Harrison (1947)].

Most of the studies on the tenderness of meat have been done on beef, and comparatively few have been reported on the effect of aging on tenderness of poultry. The work of Stewart, Lowe and Morr (1941) showed that broilers increased in tenderness after the passing of rigor. During rigor the muscles were decidedly rubbery, tough, and difficult to chew even though the birds were young. After 24 hours at 35°F., the meat changed little in tenderness up to five days. Further work by Hanson, Stewart and Lowe (1942) indicated that the tenderness of the breast of broilers increased rapidly with storage until approximately three hours. The thigh increased in tenderness more slowly; a comparable score to that attained by the breast in three hours was not

reached until after 42 hours of storage. Juiciness was not affected by the time of storage. Stewart, Lowe, Harrison and McKeegan (1945) reported that breast muscles of fowl tenderized rapidly with aging to six hours, after which the tenderizing was at a much slower rate. As in the case of the broilers, thigh muscles became tender at a slower rate. The study included 13 aging periods varying from ten minutes up to five days; the results indicated that fowl should be aged 24 to 48 hours before cooking. Aging of the fowl before cooking did not have a significant effect on the juiciness scores. In a later study on the effect of aging on tenderness of roasters aged various periods of time before cooking, Lowe et al. (1946) obtained results similar to those obtained with hens except that the rate of tenderizing was slower in the hens than in the roasters.

Chemical changes in aging

The principal chemical changes occurring during the ripening of meat include some evaporation of water, slow rise in pH, and changes in the proportions of the nitrogen fractions, with increase in the soluble nitrogen. The extent of the changes depends on the length of storage, as there seems to be no appreciable change in the proteins of beef during the first few days of storage. Emmett and Grindley (1909) studied the influence of storage on beef and poultry and

reported that the real changes were a distinct increase in the inorganic phosphorus and a decrease in the non-nitrogenous organic extractives. Hoagland, McBryde and Powick (1917) carried out an extensive investigation on the changes in beef during cold storage. They found evidence of increases in acidity, in proteose, noncoagulable amino and ammoniacal nitrogen, and in soluble inorganic phosphorus. Decreases occurred in coagulable nitrogen and in soluble organic phosphorus. All changes were of a progressive nature.

The course and extent of such complex reactions would vary considerably with time and temperature. Practically no studies on chemical changes have been made in over 20 years and during this time there have been great improvements in methods of analysis, especially for proteins so that any studies made now should yield interesting results.

Histological changes during aging

The autolytic changes which occur in tissues held at temperatures just above freezing involve the resolution of rigor and subsequent partial breakdown of the muscle fibers and connective tissue. These changes increase the tenderness and may increase the juiciness and improve the flavor of the meat. An early study by Pennington (1908), investigating the histological changes taking place in frozen poultry,

reported the following for the fresh chickens used for comparison:

> There is a certain amount of pulling apart of the individual fibers, due probably to desiccation, but at no time is there seen the granular, amorphous exudate between them. . . . One of the most pronounced differences between the appearance of the sections from cold-stored chickens and from those which have decomposed at ordinary temperatures (20°C.) is the complete annihilation in the latter of certain fibers leaving, as seen in the cross sections, occasional empty spaces, though the surrounding fibers may be in a very fair state of preservation.

Hanson (1941) reported a study in which the histological samples were obtained from both the cooked and the uncooked muscle of broilers aged from six to 40 minutes after killing and up to 118 hours. This procedure would give a much better histological picture than that obtained by Pennington (1908), who apparently used only samples of uncooked muscle removed every 12 hours. Hanson described the histological appearance of the cooked muscle of broilers stored at 1.7°C. for varying lengths of time as being characterized by increased replacement of the cross striae with granular material with increased storage time. The disintegration occurred more slowly in the uncooked than in the cooked fibers. These changes appeared to be correlated with changes in tenderness of the muscle. Fitzgerald and Nickerson (1939) reported maximum tenderness of broilers stored two to three days at temperatures near freezing.

Stewart, Hanson, Lowe and Austin (1945) and Lowe et al.

(1946) have reported the effect of aging on tenderness of roasters and fowl. They observed that the onset and rate of disintegration varied from bird to bird, but disintegration was progressively more extensive with increased aging of the birds. Disintegration in short-time aged carcasses was characterized by short strips of granular material in one or more fibers. As aging proceeded these strips became longer and more frequent. Unlike the onset of rigor, disintegration did not appear to be hastened by cooking. However, cooking seemed to increase the amount of granular material within the disintegrated areas. Disintegration paralleled or closely followed onset of rigor. It is not known whether disintegration is dependent on or independent of onset of rigor.

The cause of disintegration is probably autolysis by proteolytic enzymes during the aging period. The increased acidity would bring about a more optimum pH for the action of pepsin.

There was a wide variation in the time at which disintegration of cross-striae was observed in different birds. In general, it was earlier in the roasters than in the hens and earlier in the breast muscles than in the thigh muscles. Disintegration appeared as early (perhaps earlier) in broilers as in roasters. The increase in disintegration of a particular muscle was paralleled by the increase in tenderness of that muscle. The comparative rate for

tenderizing of muscles of birds of different ages is shown by the average tenderness scores. An average score of eight was given for the pectoralis major muscle of broilers aged three hours, for the roasters aged 12 hours and for the fowl aged 48 hours (Lowe et al., 1946).

Enzymes

In all living tissues the enzymes present function as promoters or catalysts of the large number of different chemical processes which occur in cellular metabolism and growth. The individual enzymatic reactions are controlled in the intact cell in such a manner that the intermediate products do not accumulate. When the cells are damaged by freezing or mechanical injury, these intermediates may appear. Furthermore, enzymes, like catalase and peroxidase, may become activated and produce abnormal changes. During aging or upon injury, the naturally occurring enzymes may produce profound decomposition resulting in solution of the cell contents and even of the cell walls. This type of decomposition is known as autolysis. For example, cathepsin, whose probable role in the living cell is the synthesis of proteins, apparently induces autolysis of the proteins during the ripening of meat, thus increasing the tenderness of meat.

The enzymes which are involved in the degradation of

proteins and their split-products are called proteases. Among the proteases, the proteinases, enzymes that hydrolyze true proteins, are usually distinguished from the peptidases, which attack the protein decomposition products, such as the di- and polypeptides. The proteinases have been classified into four general types by Ball and Kies (1946):

1. Proteinases most active in neutral or slightly alkaline media, the trypsinases or tryptases.
2. Proteinases most active in highly acid media, pepsin.
3. Proteinases inactivated by oxidants, and activated by reducing agents such as sulfhydryl and cyanide, papainases.
4. Proteinases of cellular origin, . . . with hydrogen-ion optima at weakly acid levels, cathepsins . . . . being cell proteinases, are endoenzymes as compared with the proteinases of body fluid.

Smorodintsev and Nikolaeva (1942) have reported results of experiments which indicate that the autolysis in the tissues does not continue at the expected rate after death. They found that in the ripening of beef, the cathepsin, the main proteinase of muscle tissue, activity decreases, even though the pH of meat is optimal for its action. These same workers state in an earlier report (1936) that the activity of cathepsin is reduced 40-45 per cent in the first 24 hours of aging and an additional 20 per cent during the next five days. The activity of trypsin, on the other hand, increases for the first 24 hours, then drops shortly thereafter. Pepsin activity increases steadily, reaching 2.5 times its initial value after the first ten days. The

occurrence of autolysis in poultry is shown by the increase in tenderness with aging especially in the case of older birds that are very tough but become more tender after aging several days.

According to Maximow and Bloom (1944), the collagenous fibers are acted upon by pepsin in acid solution but not by trypsin in weakly alkaline solution. The elastic fibers are slowly digested by pepsin and more rapidly by trypsin. The amount of lactic acid produced post mortem, and hence the pH attained, depend on the glycogen content of the tissues at death. However, after an animal is killed the pH usually drops from 7.4 to about 5.5 to 5.7. This increase in acidity should favor the breakdown of connective tissue by pepsinases if autolysis proceeds at the same rate after death as it does in the living animal.

The functioning of enzymes at temperatures below 0°C. has long been recognized by those interested in cold storage of foods where it appears that the chief changes that occur are enzymatic. Early literature on the influence of low temperatures is summarized by Hepburn (1915). He reported that a number of enzymes survived prolonged exposure to temperatures varying from about 0°C. to as low as -191°C. (liquid air), either in tissues or in solution. Sizer (1943), in his review of the effects of temperature on enzyme kinetics, called attention to the fact that enzymes are not

inactivated by storage at temperatures as low as -186°C.

Smorodintsev (1943) reported that chemical changes which occur in storage of frozen meat at temperatures of -8° to -18°C. are due to enzyme action. Glucose progressively decreases, while lactic acid accumulates. The enzyme activity is more vigorous during defrosting than during the freezing period, with slow defrosting giving more intensive action. In 1942 Smorodintsev and Nikolaeva reported that, in a study using cow muscle for an incubation period of 24 hours, the peptidase activity was increased 25 per cent at 3°C. and 140 per cent at 37°C. After ten days at 3°C., the activity was 2.5 times that found at the time of slaughter.

Although enzyme activity may continue in the frozen state, ice formation has a marked retarding effect. Lineweaver (1939) and Sizer and Josephson (1942) pointed out that, for the few cases investigated, the velocity of enzyme reaction is faster in the supercooled state than in the frozen state at the same temperature. The velocity greatly decreases when the change of state occurs. They believe this decrease must be due to increase in the concentration of substrate and to other changes which take place in the physical and colloidal properties of a system when it passes from the liquid to the solid state.

Many observations on enzymes have been of a purely qualitative nature, and there is a need for quantitative work

on enzyme kinetics at low temperatures to furnish information of fundamental importance in the cold storage and freezing of foods. Such a study was made by Sizer and Josephson (1942) on three typical enzymes--pancreatic lipase, trypsin and yeast invertase--which attack fats, proteins and carbohydrates respectively, over the temperature range from 50° to -70°C. They found a sharp change in the temperature kinetics about -2°C. so that calculations of enzyme activity at low temperatures based on measurements at higher temperatures are unreliable. They state:

> The high activation energies for these enzyme systems at low temperatures should be of special interest to those concerned with the storage of foods and other biological materials at low temperatures, since it means that relatively small decreases in temperature below freezing will be relatively very effective in retarding undesirable enzyme action. For lipase, trypsin and invertase a unit decrease in temperature below -2°C. is roughly five times as effective in retarding enzyme action as a similar decrease in temperature above 0°C. Studies reported in this paper clearly indicate, however, that enzymes are not in any way destroyed by very low temperatures, so that when cold storage foods are returned to normal temperatures, enzyme action will regain its original rate.

In a study of frozen poultry (Hoffman, 1939) which had developed a very powdery texture, the microscopic examination of the tissues showed that elastic fibers had been acted upon by an enzyme or enzymes and had fallen apart in tiny rodlike shapes. Lowe (1943) has suggested enzyme action as a cause of the partial disintegration. Since this type of partial

disintegration has only been observed in frozen poultry, the proteolytic enzyme acting on elastin apparently must be active at low temperatures.

Rate of Freezing

Some of the early investigators froze gels in an attempt to determine the effects of freezing on a hydrosol. Such an experiment was performed by Moran (1929) in which he found that freezing was intermittent, i.e., centers of crystallization formed which were filled with a solid solution of ice and gel and between these spaces were areas of homogeneous gel. This is surprisingly similar to the effect of freezing on muscle tissue, but the muscular system is much more complex and requires study of the particular tissue involved as apparently not all animal tissue behaves the same under similar conditions of freezing. In a study of ice formation, Moran (1931) found that in the same piece of meat frozen at -4°F. large crystals were formed in the center of the sample, whereas, on the outside layer, where time required for freezing was shorter, the ice crystals were very small. Moran (1932) also reported that at -5°C. approximately 82 per cent of the water in meat was frozen; more water was frozen at lower temperatures, but a smaller per cent in relation to the reduction in temperature.

There are many factors which affect the time of cooling

or the rate of freezing. Stiles (1922) grouped these factors into two classes: internal factors depending on the nature of the cooled substance, the product, and external factors depending on the properties of the cooling medium. Any property of the product affecting its heat capacity or conductivity will also affect the precooling time. Such factors as thermal conductivity, specific heat, latent heat, specific surface and the nature of the surface would be included under the first class. Thus the initial temperature and weight of the bird can be estimated quantitatively and related to the time required for both precooling and freezing. However, other factors such as the shape of the bird, which would affect the surface-to-volume ratio, and the content and distribution of moisture and fat in the carcass cannot be measured with sufficient precision to determine their influence on the cooling rate. In most cases the properties of the cooling medium are comparatively well understood and more easily controlled.

In addition there are a number of factors which affect the rate of freezing of meat at any given freezing temperature. The freezing rate may be increased by 1) using packaging materials with low insulating value, 2) preventing air pockets within the package, 3) using methods which accelerate the transfer of heat, and 4) reducing the size or thickness of the product or removing any excess fat.

The terms fast freezing and slow freezing have been used vaguely and have no definite meaning. According to Moran (1932) meat is quick frozen if it is chilled through the temperature range of 41°F. to 23°F. in one-half hour or less. Quick freezing is defined by Poole (1935) as freezing by any method in which the "zone of maximum crystal formation" or solidification (31° to 25°F.) is passed through in a short time, about one-half hour or less for most desirable results.

Hence, the size and location of ice crystals in frozen tissue will depend on the rate at which the temperature of the meat is dropped from just above the freezing point (30°F. for beef) to approximately 25°F. The ice crystals will be smaller if the temperature of the meat is reduced through this zone quickly, than if the temperature is reduced slowly. In addition to the effect that the rate of freezing has on the ice-crystal pattern, the length of time between slaughter and freezing is important. Ramsbottom and Koonz (1940) have shown the microscopic appearance of ice crystals in steaks frozen at -30°F. at six hours, one day and 35 days after slaughter. The ice crystals are progressively larger as the time between slaughter and freezing is increased. They attribute this phenomenon to the physico-chemical changes which take place in the muscle during and following rigor mortis. Chambers and Hale (1932), in an interesting study of the formation of ice in protoplasm, concluded that the

sarcolemma of the cytolysed muscle fiber may serve as an obstacle to internal freezing but not so efficiently as that of a living cell. So the histological structure also enters into the determination of the ice crystal formation. The elasticity of the sarcolemma apparently permits the individual fibers of muscle to withstand considerable internal pressure from ice columns, which accounts for the difference between the effects of freezing on muscle and on vegetables and fruits, in which the cell walls are not elastic and consequently are often ruptured.

Many cuts of meat, particularly steaks and chops have a large area of cut surface in relation to volume of meat. It has been found by a number of investigators that rapid freezing or intra-fibrillar freezing is desirable if drip is to be held at a minimum after these products are defrosted. However, this is not true for poultry, as has been pointed out by Sair and Cook (1938) and Koonz and Ramsbottom (1939). Poultry meat does not drip noticeably unless the muscle has been finely minced, a treatment that would hardly be used except for experimental purposes. Apparently freezing rates are not so critical in the case of poultry as they are for some cuts of meat and for certain fruits and vegetables.

Effect of Freezing on Tissue

In considering the effect of freezing on tissue, the change in structure is important in determining how nearly meat will resemble unfrozen meat when thawed. Plank (1925) points out the importance of two effects of freezing: the damage to the protoplasmic structure by formation of ice crystals and the consequent dehydration of the colloid.

Chemical changes

According to Moran (1935) freezing promotes denaturation of the muscle proteins and this denaturation of the muscle proteins is maximal at a temperature in the range -2° to -3°C. Work reported by Smorodintsev (1943) indicated that meat proteins are not cleaved or denatured by the freezing process. The changes due to enzyme action were progressive decrease in glucose with an accumulation of lactic acid. Considerable enzymic cleavage of phosphatides occurred on storage, but the cleavage did not reach the inorganic phosphate stage. Undoubtedly more work is needed along this line and newer methods of protein analysis should give more reliable results.

Histological changes

As long ago as 1908 Pennington reported a histological

study on chickens frozen at -15°C. compared with fresh birds. She found that simple freezing caused a slight pulling apart of the fibers, but they retained their integrity. However, after only one month of storage at -10°C., she observed indications of an autodigestion which resulted in the presence of homogeneous protein material between the bundles of fibers, and later the sarcolemma ruptured, permitting the exudate to stream from the end or sides. Later work by this same worker (Pennington et al., 1917) reported the same characteristic changes in histological structure. Sherrill (1928) showed that slow freezing damages the muscle structure of haddock. Vickery (1926) also emphasized the importance of the effect of freezing on the sarcolemma; his work indicated that the sarcolemma has an important role in determining the amount of reconstitution that will take place. Most of the early work is on slow freezing of food and the present trend is toward using temperatures of 0°F. (-17.8°C.) or below.

Are the changes in the tissue altered by the method of freezing and is rapid or slow freezing better? One of the early studies which attempted to answer these questions was made by Nuttall and Gardiner (1919) on the histological changes in frozen fish. They found that in rapid freezing a single column or a number of small columns of ice were formed in each muscle fiber. The less fluid parts were pressed against the sarcolemma so the fibers simulated

hollow cylinders enclosing ice columns. There was no damage to the sarcolemma, whereas in slow freezing it was ruptured. Lampitt and Moran (1933) studied the quality of slowly and rapidly frozen beef and lamb. Although they observed a marked difference in the appearance of microscopic cross sections of the frozen meat samples, the palatability tests showed that there was no marked preference for either the rapid- or slow-frozen samples.

Dubois, Tressler and Fenton (1942) studied cross sections of chicken after freezing with different methods and conditions. Chickens were frozen with the Birdseye multiplate freezer, and in air with and without air blast at -10°, -8° and -25°F. Large ice crystals were found in the tissues frozen slowly at -10°F., whereas the faster methods effected the formation of a large number of very small crystals. Koonz and Ramsbottom (1939) also studied frozen sections of chicken muscle. They reported that if small pieces of poultry muscle are frozen almost instantaneously, the water freezing within the fibers appears as minute, evenly distributed ice columns. If the temperature is raised, the water will be displaced to the center of the fiber and will appear as a single, large, centrally located ice column parallel to the long axis of the fiber. When the freezing is slow, the water will be lost by the fibers and will freeze external to the fibers. Whole birds frozen at -32°F. showed

intra-fiber freezing in some of the fibers, whereas other fibers lost water which froze external to the fibers. In birds frozen at -15°F. extra-fibrillar freezing occurred exclusively. The authors point out that very slowly frozen poultry appears dark, with very large ice crystals of the extra-fibrillar type. When poultry is frozen at a temperature that insures a rather natural bloom, the ice crystals are smaller and more numerous, but are still principally of the extra-fiber type.

The conditions and influences that may affect the distribution, size and number of ice formations in frozen poultry are many. Shrewsbury et al. (1942) found that pork tissue frozen at -29°F. presented a varied histological appearance from even distribution of undamaged cells, to cells with small vacuoles and sarcolemma intact or distorted cells with damage to their outer surfaces. From the evidence they concluded that freezing pork muscle at -26°F. produced both extra-fibrillar and intra-fibrillar freezing, and the extent and type of tissue damage varied considerably within and between animals. One important factor in determining the size and location of ice crystals which has not been considered by most workers is the time between slaughter and freezing. Ramsbottom and Koonz (1940) showed that ice crystals became progressively larger in beef steaks as the time between slaughter and freezing increased. They state that a microscopic study of the tissues showed that

intra-fibrillar freezing occurred in steaks frozen at -30°F. six hours after slaughter. However, in steaks held one day before freezing at the same temperature, -30°F., extra-fibrillar freezing was predominant. This was also true for all steaks frozen longer intervals. Further, they found the extra-fibrillar ice crystals in the steaks were rather small when frozen one day after slaughter, becoming progressively larger as the time between slaughter and freezing increased. They remarked that these findings were also true for poultry but gave no experimental evidence. Stewart, Hanson, Lowe and Austin (1945) have presented evidence to prove that time between slaughter and freezing, as well as the freezing temperature, affects the histological appearance of muscle fibers and the location of ice crystals.

> All birds frozen at -67.8°F. within two hours after slaughter had vacuoles within the fibers of breast and thigh muscles. The vacuoles were very numerous in both raw and cooked sections from some broilers, less so in other broilers. . . . These vacuoles were considered an indication of intra-fibrillar freezing, ice crystals having formerly occupied the site of the vacuoles. Intra-fibrillar freezing also occurred in all breast muscles and half of the thigh muscles of broilers frozen within two hours after killing at -45.5°C. No intra-fibrillar freezing occurred in broilers frozen within two hours after killing at -20.5°C. In general, intra-fibrillar freezing did not occur in any broilers held 18 hours before freezing, regardless of the freezing temperature used.

Effect of Freezing on Tenderness

The results of most of the studies on the influence of freezing on the quality of meat have shown that freezing tenderizes meat. As early as 1907 Lehmann noted that freezing increased the tenderness of beef and that the effect was greater in the less tender muscle or "flank" than in the loin muscle. Tressler, Birdseye and Murray (1932) found that quick freezing of beef and subsequent storage at -0.4°F. had a tenderizing effect. Paul and Child (1937) reported that beef frozen at -2.2°F. was not tenderized. However, the longissimus dorsi muscle from rolled rib roast aged ten days was used for their study so that a comparatively tender muscle may have reached its maximum tenderness before it was frozen. Hankins and Hiner (1938) found that freezing short loin steaks, aged 96 hours, at 20°, -10° or -40°F. increased the tenderness when compared with those held at 34°F.

The time of aging before freezing will condition the tenderizing effect, so in any study of the effect of freezing on tenderness the time between killing and freezing should be considered as an important factor affecting the final result. Hiner and Hankins (1941) reported that beef samples stored at 33° to 35°F. for five, 15, 25, and 35 days became more tender with aging. The tenderness was further increased by subsequent freezing, but to a decreasing degree

with increasing storage time.

Most of the studies on the effect of freezing on tenderness have been made on beef, and relatively little information exists concerning the influence of aging before freezing on the tenderness of chickens. In a study on the effect of drawing before freezing on the palatability of poultry, Hoffman (1939) found that roasters chilled overnight were more tender than those frozen within two hours after killing. In a review of this study Lowe (1939) remarked that the mean scores for tenderness indicated that the birds frozen a second time were somewhat more tender than those frozen only once before drawing. In their study on the effect of rate of freezing and the temperature of storage on the quality of frozen poultry, Dubois, Tressler and Fenton (1942) did not discuss the effect on tenderness. However, an examination of the scores given in their report reveals that nine out of the 11 freezing methods employed had scores from 0.4 to 1.5 higher than the 5.1 score for tenderness of the fresh chicken (7.0, highest possible score). Stewart, Hanson, Lowe and Austin (1945) reported that freezing broilers at -5°, -50° and -90°F. caused no significant differences in the tenderness of the breast muscle. However, the thigh muscles of the fresh controls were rated less tender than the corresponding muscles in the frozen birds.

Wills (1946) found fryers eviscerated and frozen within

two hours after killing were less tender than similar fryers held 24 to 48 hours before eviscerating and freezing.

METHOD OF PROCEDURE

History of the Birds

The 50 chickens used for this study were obtained at the Iowa State College farm. The roasters, 24 Rhode Island Reds and six Barred Rocks about five to eight months old at the start of the study, were killed, frozen and cooked between January 6, 1947, and February 10, 1947. The 20 fowl, White Leghorns ranging in age from 20 months to two years, one month, were killed, frozen and cooked between February 17, 1947, and March 12, 1947. All the chickens received similar rations of 18 per cent protein mash and grain, consisting of one-half corn and one-half oats. Thus any differences between birds would be due to factors other than feed.

Preparation for Cooking and Freezing

Killing and aging

The birds were killed at the Poultry Laboratory with the exception of a few in the 30-minute group killed in the Home Economics Laboratory. After killing, the chickens were held firmly by the neck and legs, head down, while they bled for one minute. They were immediately scalded by plunging

in two gallons of water at 138°F. (58.9°C.) in which they were agitated for one and one-half minutes. Next the birds were dressed and eviscerated and, after washing inside and outside with lukewarm running tap water, were placed in pliofilm bags for aging. The aging periods (time between killing and freezing) used were 30 minutes, and one, two, six and 24 hours. The 30-minute and the one- and two-hour groups were aged at room temperature, and the six- and 24-hour groups were aged in the refrigerator at 39.2°F. (4.0°C.).

Thirty minutes before the end of the aging period, the chickens were cut in half prior to freezing and cooking with the exception of the 30-minute group, which were halved 15 minutes before cooking and freezing. The birds were cut in half in an attempt to eliminate some of the differences resulting from the great variation between individual birds.

Cutting the chicken in half

Since the keel bone could not be cut in half, the cut was made as close to the bone as possible. Thus one side of the chicken had the keel bone intact which protected the breast muscle, whereas on the other half of the bird the breast muscle was cut and exposed. To provide a covering to protect this cut surface, the neck was cut off close to the body and the skin from the neck was brought down over the body cavity and sewed to the skin on the breast. (The

half of chicken with the bone in was treated similarly.) See Figure 1. Another factor to consider in cutting the birds in half was the effect of cutting the muscle a short time after slaughter. Studies by Lowe and Stewart (1946) have shown that if breast muscles of roasters are cut soon after slaughter, a toughness often develops along the cut surface which persists even after aging and cooking. In order to minimize the effect of cutting the muscle and of having the keel bone only on one side, the treatment of the cut side was alternated so that approximately one half of the cut sides were used as fresh controls and an equal number of cut halves were frozen. However, when both sides of the bird were frozen, the cut side was frozen at -30°F.

After the bird was cut in half, a small histological sample was removed from the pectoralis major muscle about one inch anterior to the sternal crest of each half of the bird. Then the neck skin was pulled down over the body cavity, and both halves were sewed as shown in Figure 1. A constantan-copper thermocouple for recording the rate of freezing was placed in the thigh of the half to be frozen. This half was then put in a pliofilm bag, the sides of the bag were pressed against the chicken to exclude all air possible, and the bag was tied securely with string. See Figure 2.

At the end of the aging period, one half of the bird was used as a fresh control and was cooked. The other half of

Fig. 1. Showing a half of chicken ready for cooking.

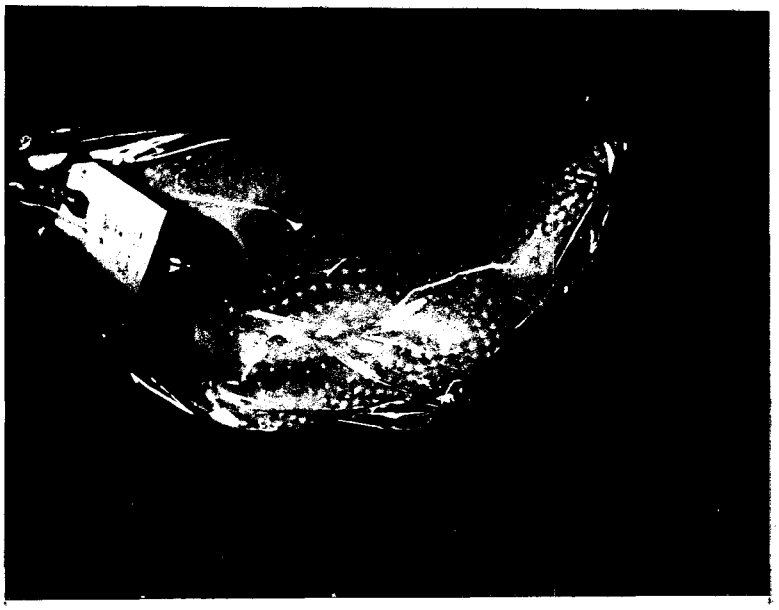


Fig. 2. Showing a half of chicken with the thermocouple in the thigh and in a pliofilm bag ready for freezing.

the bird was frozen. At the end of 24 hours, the frozen half of chicken was thawed (24 hours) and then cooked. In this study no attempt was made to separate the effects of freezing from the effects of thawing.

Freezing and Thawing

All the halves of birds were frozen in the Iowa State College experimental freezing unit. They were held for 24 hours either in the sharp freezing unit at -30°F. (-34.4°C.) or in the 0°F. (-17.8°C.) room. Two roasters and two fowl were cut in half, and one side was frozen at each temperature for each of the five aging periods, making a total of four replications for each treatment. For this part of the experiment a total of 40 halves of chicken were frozen and 40 halves were cooked. This meant that each half of chicken that was frozen could be compared with the corresponding fresh half of chicken for palatability, shear force and histological appearance. In the case of 10 roasters both sides of the bird were frozen, one at -30°F. and one at 0°F. Two replications were made at each aging period. In this part of the study, the half of bird frozen at -30°F. could be compared with the half frozen at 0°F.

These treatments were randomized so no particular sequence was followed for aging or freezing. Also the halves of birds were given a code number so the judges were not

aware of the treatment the birds received.

At the end of 24 hours, the frozen half of chicken was taken from the freezer locker to the Home Economics laboratory. A histological sample was sawed out about one inch anterior to the sternal crest, a spot corresponding as nearly as possible to the place where the sample had been removed from the other half of the bird used as a fresh control. See Figure 3. As soon as the sample was removed, the half of bird was put in the refrigerator to thaw for 24 hours at 39.2°F. (4.0°C.).

Rate of freezing

The drop in temperature occurring during the freezing of each of the birds was measured by means of a Leeds and Northrup Micromax (calibrated in degrees Fahrenheit). Each freezing room had six sets of poles connected to the Micromax. The constantan-copper thermocouple, placed in the thigh of each half of bird before wrapping, was attached to one of the sets of poles and the temperature was automatically recorded every six minutes on a moving roll of paper calibrated in degrees Fahrenheit. Freezing curves were made from these detailed data.

Cooking

The weight and temperature of each half of chicken were

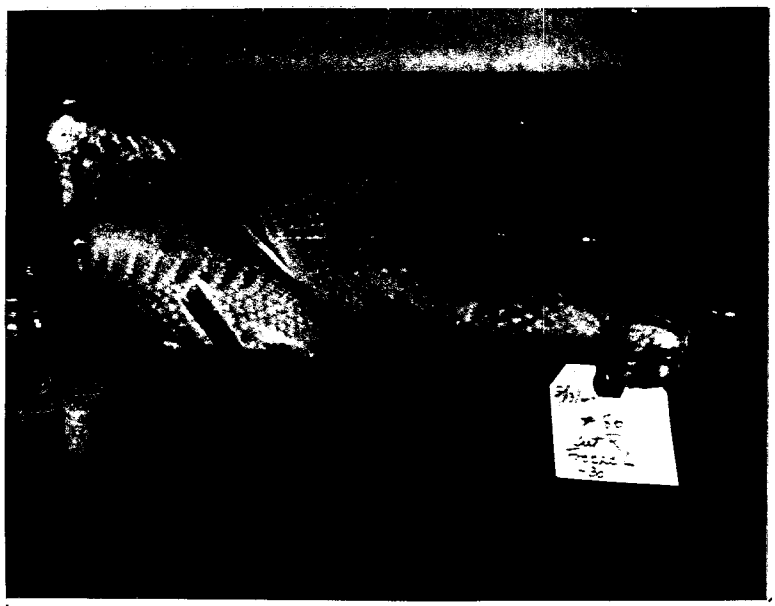


Fig. 3. Frozen half of bird showing location from which histological sample of the uncooked breast muscle was obtained.

recorded just before cooking. A thermometer, six inches long with a short bulb, was inserted into the center of the thigh parallel to the breast bone. The half of bird was placed breast side down on a wire rack about one-half inch above the bottom of a shallow, uncovered pan. The dimensions of the oval-shaped pans were: long diameter, 15 inches; short diameter, 12 inches; height, 1.75 inches. All halves of birds were roasted in the oven at a temperature of 150°C. (approximately 300°F.) until the thermometer in the thigh registered 195°F. Ordinarily fowl are braised (covered and cooked slowly with some added moisture), but for this study roasting was used because it was a more uniform method in which the procedure was easier to standardize and the temperature regulation more accurate. Temperatures of the oven and the bird were recorded every 20 minutes. When the thermometer in the thigh read 195°F., the halves of birds were removed from the oven. The weight of the half of bird was recorded and then the weight of the pan, rack and drippings. From these weights the cooking losses were calculated.

The total cooking losses of all samples were calculated as the difference between the weights of the raw and the cooked halves of chicken. The loss as drippings was taken as the differences in weight between the roasting pan and rack containing the drippings and the empty pan and rack. The volatile loss was calculated as the difference between

total cooking loss and the drippings. The percentages of all losses--total, drippings and volatile--were calculated on the weight of the uncooked chickens.

Methods of Testing

Scoring

The pectoralis major, the large breast muscle (Figure 4), and the pectoralis secundus, just under the pectoralis major (Figures 5 and 6), were the two muscles used for scoring by a group of four judges. Palatability of the chickens was considered to be dependent upon the four factors: aroma, flavor, tenderness and juiciness. Each of these four factors was judged on a basis of ten points so that a perfect bird would have a score of 40 points. The scores were recorded on a score sheet similar to the one included in the appendix.

In removing the muscles for judging, the skin of the cooked bird was pulled back and the muscles removed by cutting as close as possible to the keel bone and the wish bone. See Figure 4 or 5. The anterior tip ends of both muscles were always discarded because of their heavy connective tissue. Each judge was always given the same section of the muscle to judge; that is, the first cut from the anterior portion of the muscle was always given to one judge, the second judge received the second cut, and so on. After the

Fig. 4. Pectoralis major muscle of the breast.

Fig. 5. The pectoralis secundus muscle. The pectoralis major muscle has been removed entirely.

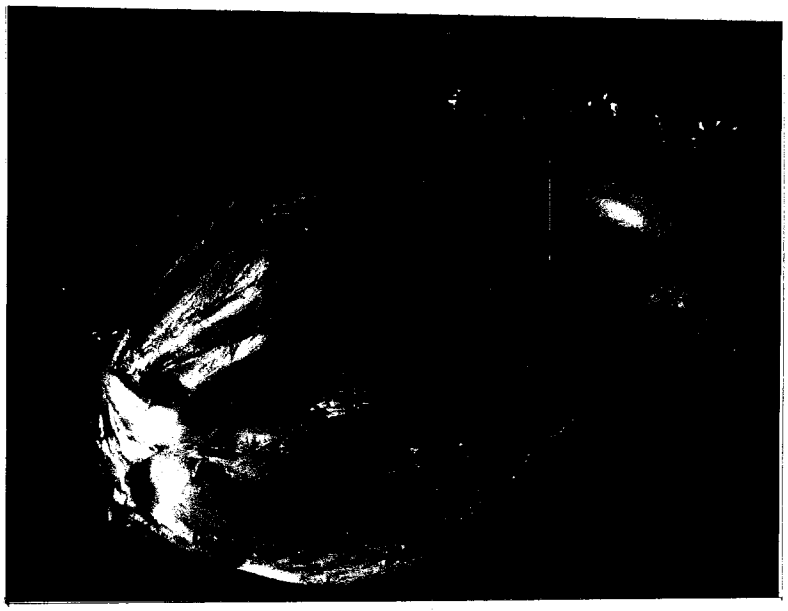


Fig. 6. The pectoralis major muscle partially removed, showing the pectoralis secundus muscle beneath it.

judges' samples were taken from the pectoralis major, a small histological sample was cut and the rest of the muscle was carefully wrapped in wax paper and stored in the refrigerator until sheared the following day.

Shearing

Shearing, as used for an objective test of tenderness, is the force in pounds required to cut across the muscle. The remainder of the pectoralis major muscle was used for shear tests. The first shear was made on the tip or posterior end of the muscle where it is only about 1/2 to 3/4 of an inch wide. Each shear was about 3/8 of an inch above the previous one. It was possible to obtain a total of six shears. The pounds required for shearing increased as the muscle increased in width and thickness. The shear strength readings for one muscle were averaged and the mean score of the force required for shearing in pounds was taken as an indication of the tenderness and compared with the judges' scores for tenderness. Hoffman (1939) has a complete description of the construction and operation of the shearing apparatus. A picture of the shearing apparatus is shown in Figure 7.

Histological studies

Four histological samples of the pectoralis major muscle

Fig. 7. The shearing apparatus.

of each bird were obtained for the histological studies: 1) from the fresh half of the bird to be cooked and from the half to be frozen, 2) from the cooked fresh control half, 3) from the frozen uncooked half of bird, and 4) from the frozen-thawed half of bird after cooking. The muscle samples were fixed in a solution composed of physiological salt solution and ten per cent formalin and stored in small bottles.

All the sectioning of the chicken tissue was done on the freezing microtome. The cooked muscle was cut 15 microns thick and the uncooked was cut at 25 microns. The muscle was stained with Harris' alum hematoxylin for studying the muscle fibers. Each sample was also stained with Harris' alum hematoxylin and Van Geisen's mixture of acid fuschin and picric acid so the distribution of the collagenous fibers and its effect on the muscle could be studied. Samples from each age group were stained with Weigert's modified elastic stain and then with Harris' alum hematoxylin and Van Geisen's stain. Some of the fowl sections were stained in Herxheimer's scarlet R solution to show the distribution of fat.

After the frozen sections were cut, they were transferred to a small wire basket in which they were carried through the various solutions. The sections were extremely friable and had to be handled with great care. Glycerine jelly was used for mounting the sections.

RESULTS AND DISCUSSION

Size and Weight of Birds

All the fowl were from an inbred line of White Leghorns, which were very small. The roasters were Rhode Island Reds and Barred Rocks and were quite large birds.

The weight before cooking of the individual halves of roasters varied from 681 grams (1.5 lbs.) to 1215 grams (2.7 lbs.). The fowl were noticeably smaller. Their weights varied from 412 grams (0.9 lbs.) to 1048 grams (2.3 lbs.). The detailed data on weights are given in Tables C and D of the Appendix. The average weight of the fresh control and frozen halves of roasters and fowl for the different aging periods are given (Table 1). The difference in weight between the fowl and roasters is quite evident.

Table 1. The average weight before cooking of halves of roasters and fowl aged varying periods of time before cooking or freezing.

Aging time	Fresh control		Frozen 0°F.		Frozen -30°F.	
	Roasters	Fowl	Roasters	Fowl	Roasters	Fowl
	gms.	gms.	gms.	gms.	gms.	gms.
30 min.	871.8	661.8	904.0	659.0	954.0	593.0
1 hour	877.5	701.8	968.5	620.0	817.8	745.0
2 hours	907.8	734.8	983.3	626.0	822.3	793.5
6 hours	864.5	554.3	922.3	576.5	912.8	543.0
24 hours	952.3	633.5	951.3	701.5	887.5	615.5

The average weight of all the halves of chickens used for fresh controls was 777 grams (1.7 lbs.) as compared with 805 grams (1.8 lbs.) for the halves of carcasses frozen at 0°F. and 841 grams (1.9 lbs.) for those frozen at -30°F. See Table 4. Although there was considerable variation in weight from bird to bird, the mean weight for each treatment was practically the same.

Cooking Time

Studies have shown that the factors which affect the time required to cook poultry meat to a certain temperature are: a) the cooking temperature; b) weight of the chicken; c) the shape of the bird, short and thick or long and thin; d) fat deposition; e) the initial temperature of the bird; f) the composition of the meat; and g) the degree of post-mortem changes.

The average cooking time for the halves of roasters and fowl is given in Table 2. The shorter cooking time for the halves of fowl was to be expected because they weighed less than the roasters. The average cooking time given in Table 4 for all control halves of chicken was 114.5 minutes, for the halves frozen at 0°F., 128.7 minutes and for the halves frozen at -30°F., 136.3 minutes. The initial temperature at the start of cooking was lower for the thawed halves than for the control halves; hence they required a

Table 2. The average cooking time of halves of roasters and fowl aged various periods of time before cooking or freezing.

Aging time	Fresh control		Frozen 0°F.		Frozen -30°F.	
	Roasters	Fowl	Roasters	Fowl	Roasters	Fowl
	min.	min.	min.	min.	min.	min.
30 min.	133.3	99.0	150.8	96.5	165.2	120.0
1 hour	138.8	96.3	157.8	103.5	131.0	101.5
2 hours	121.8	87.0	151.3	95.0	140.8	115.0
6 hours	124.2	93.0	149.2	120.0	128.2	95.0
24 hours	142.5	105.5	136.2	140.0	133.8	101.0

longer cooking time. The variation in cooking time within each group indicates that aging did not have any appreciable effect on cooking time.

Cooking Losses

The data on the cooking losses are presented in Table 3. The average values indicate that freezing did not appreciably affect the percentage of cooking loss for either the roasters or the fowl. The changes attributable to aging or freezing are either too small or too variable to be significant. However, it should be noted that for both roasters and fowl the cooking loss for those aged six hours is less than for the 24-hour group. However, the halves aged 24 hours weighed more, hence required a longer cooking time.

Since the birds in this study were halved, there was a large cut surface on the breast muscle of the half of bird from which the keel bone was separated. This increased the

Table 3. The average total cooking losses of halves of roasters and fowl aged varying periods of time before cooking or freezing

Aging time	Fresh control		Frozen 0°F.		Frozen -30°F.	
	Roasters	Fowl	Roasters	Fowl	Roasters	Fowl
	%	%	%	%	%	%
30 min.	28.5	27.5	28.4	24.3	29.3	30.3
1 hour	28.8	30.4	23.2	27.4	24.9	28.0
2 hours	28.4	25.3	28.1	27.0	29.6	26.4
6 hours	25.0	27.8	28.1	31.6	21.2	27.6
24 hours	29.6	30.5	29.6	35.9	29.0	27.8

opportunity for losses by dripping and evaporation. However, as stated previously, the cutting was planned so that an equal number of halves without keel bones were in each group and also the neck skin was sewed over the breast to minimize any losses. All birds were halved in a similar fashion; thus comparisons between groups would be valid.

Cooking losses and cooking time

Losses in weight during cooking showed a linear relationship with the total cooking time.

The data on weight, total cooking loss, cooking time and temperature relationships are summarized in Table 4. Under the conditions of this study, the average values indicate that the total cooking loss was not appreciably affected by freezing. Contrary to the usual finding, the cooking time did not decrease with aging; however, Paul (1943) found that the cooking time of beef did not decrease

Table 4. Summary of the average weight before cooking, the total cooking loss, and cooking time-temperature relationships for halves of all chickens aged varying periods of time before cooking or freezing and cooking

Time of aging	Weight before cooking	Total cooking loss	Time of cooking	Initial temperature	Total temperature rise	Temperature rise per min.
	gms.	%	min.	°F.	°F.	°F.
Fresh control[1]						
30 min.	766.8	28.0	116.1	88.7	106.3	0.960
1 hour	795.9	29.6	117.5	75.6	119.4	1.046
2 hours	821.2	26.8	106.1	77.9	117.1	1.183
6 hours	709.4	28.4	108.6	60.1	135.0	1.336
24 hours	792.9	30.0	124.0	49.1	145.9	1.255
Average	777.2	28.6	114.5	70.3	--	--
Frozen -30°F.[2]						
30 min.	833.6	29.5	150.2	32.6	162.4	1.103
1 hour	793.5	25.9	121.2	35.3	159.7	1.361
2 hours	812.7	28.5	132.2	37.7	157.3	1.255
6 hours	789.5	25.0	117.2	35.9	159.1	1.410
24 hours	796.8	28.6	122.8	42.2	152.8	1.283
Average	805.2	27.5	128.7	36.7	--	--
Frozen 0°F.[2]						
30 min.	822.3	27.7	132.7	35.9	159.1	1.268
1 hour	852.3	24.6	139.5	35.0	160.0	1.248
2 hours	857.5	27.7	132.5	34.2	160.8	1.274
6 hours	807.0	29.3	139.5	38.9	156.1	1.186
24 hours	868.0	31.7	137.5	41.3	153.7	1.121
Average	841.4	28.2	136.3	37.0	--	--

[1]Average of 4 halves of roasters and 4 halves of fowl.

[2]Average of 4 halves of roasters and 2 halves of fowl.

with increased storage. The cooking data indicated that the muscle fibers in the frozen-defrosted birds were able to retain the reabsorbed water as the cooking losses were similar for the frozen and fresh control chickens. This is in agreement with the results of Koonz and Ramsbottom (1939).

The detail data for individual birds, including the volatile and dripping losses, are given in Tables C and D of the Appendix. The volatile loss accounted for a large part of the total cooking loss. The average volatile loss ranged from 17.3 to 23.3 per cent as compared with 6.3 to 9.0 per cent for dripping loss.

Appearance

The rate of freezing did not affect the appearance of the birds as there was no indication of loss of bloom in the halves of chickens frozen at 0° or at $-30^{\circ}F$.

Palatability Factors

The pectoralis major and the pectoralis secundus muscles of the halves of chickens were judged for tenderness, juiciness, flavor, and aroma. Each factor was scored from one to ten with the exception of tenderness in the fowl in which case minus scores also were used. This was necessary because some of the fowl were quite tough and the range of one to ten used for scoring tenderness in the roasters did not allow

sufficiently low scores to adequately indicate the toughness in the fowl. The values assigned for tenderness scores were based on the number of "chews" necessary for complete mastication of a piece of chicken meat. Each judge set up her own standard. The data for palatability scores for individual birds are given in Tables A and B of the Appendix.

Aroma and flavor

The average aroma and flavor acores for the two cooked breast muscles of the halves of the fresh control and frozen birds are given in Tables 5 and 6 and are shown graphically in Figure 8. There is practically no difference in the aroma scores. In general the flavor scores were similar to the aroma scores, showing little variation between treatments.

Table 5. Average palatability scores of pectoralis major muscle of the halves of all the chickens aged various periods of time before cooking or freezing

Time of aging	No. of halves	Aroma	Flavor	Tender-ness	Juici-ness
Fresh control					
30 min.	8	8.9	8.7	1.2	7.2
1 hour	8	8.8	8.2	1.6	5.6
2 hours	8	8.7	8.3	1.6	6.2
6 hours	8	8.7	8.6	6.6	6.3
24 hours	8	8.9	8.4	8.7	5.2
Frozen 0°F.					
30 min.	6	9.0	8.7	8.6	6.2
1 hour	6	8.9	8.8	7.2	5.9
2 hours	6	8.9	8.5	8.0	5.3
6 hours	6	8.9	8.6	8.2	5.0
24 hours	6	8.9	8.4	8.3	4.3
Frozen -30°F.					
30 min.	6	9.0	8.6	8.0	5.5
1 hour	6	8.9	8.4	8.2	6.0
2 hours	6	8.9	8.7	7.8	5.9
6 hours	6	9.0	8.7	7.0	6.1
24 hours	6	8.8	8.6	8.2	5.4

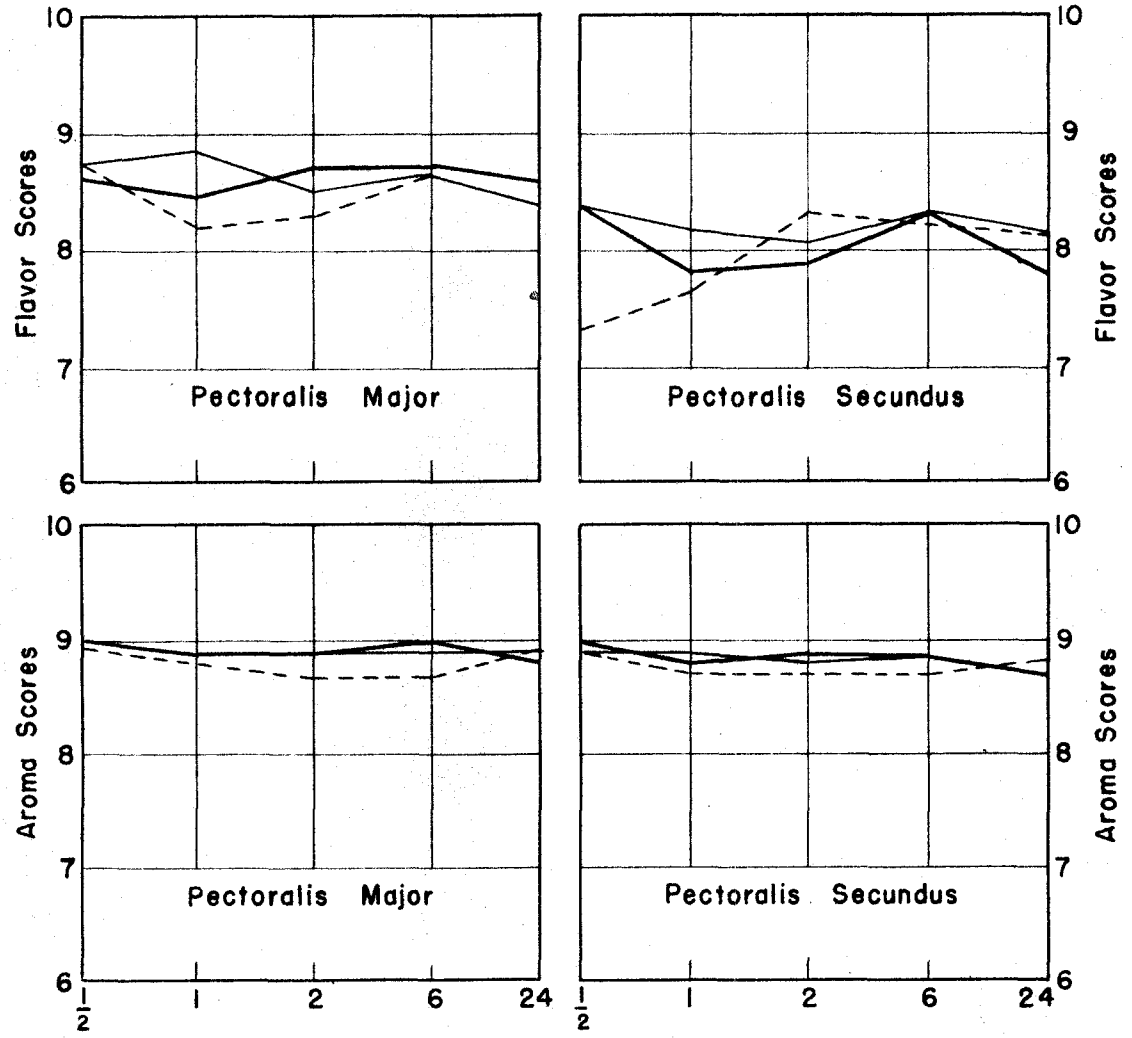


Fig. 8. The effect of aging various periods of time or aging, freezing and thawing on the mean flavor and aroma scores of the two breast muscles of the halves of chicken.

Juiciness

The amount and state of free and bound water in the muscle would affect juiciness. Johnson (1946) determined by vapor pressure methods the amount of bound water in the pectoralis major muscle of roasters. She found that there was a greater binding of water with longer storage and at higher storage temperatures. Also the quantity of bound water was noticeably increased by cooking. The factors affecting juiciness also include feed, finish and fat distribution, extent of cooking and the treatment of the bird, such as aging or freezing. In view of these and other factors, it is apparent that the only way to obtain valid comparisons between treatments is to divide the birds in half.

The average scores for juiciness of the two cooked breast muscles of the halves of all the fresh control and frozen birds are given in Tables 5 and 6. The juiciness scores are shown graphically in Figure 9.

The pectoralis major. The juiciness scores of the fresh control halves decreased from 7.2 at the 30-minute aging period to 5.2 after aging 24 hours, an over-all decrease or two points. However, there were some variations in the juiciness scores for the aging periods between 30 minutes and 24 hours. The juiciness scores of control halves aged one hour decreased to 5.6; then the juiciness increased with aging until six hours (6.3), when it decreased again to 5.2

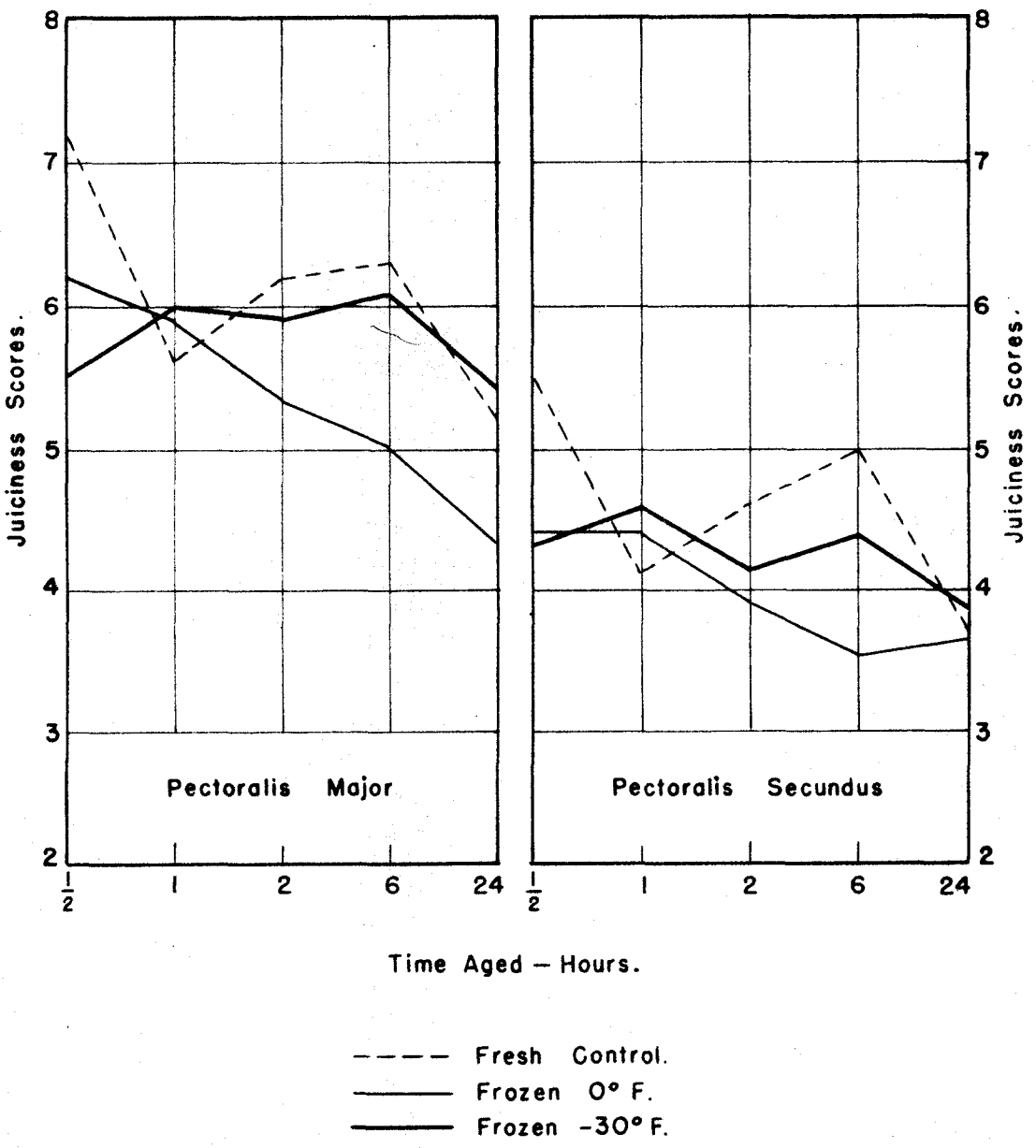


Fig. 9. The effect of aging various periods of time or aging, freezing and thawing on the mean juiciness scores of the two breast muscles of the halves of chicken.

for the birds aged 24 hours. Stewart, Lowe, Harrison and McKeegan (1945) found a downward trend in juiciness scores of the pectoralis major muscle with aging of fowl, but the variations were not significant. Lowe, Stewart, Harrison and McKeegan (1946) found a trend for juiciness scores of roasters to increase with aging. Since juiciness of the muscle is affected by fat distribution in the carcass, the time of cooking, cooking losses and other factors, it is not surprising that results are not in agreement in different studies, particularly when the variation in results has not been statistically significant.

The juiciness scores of the pectoralis major muscle of the halves frozen at 0°F. showed a steady decrease as the ripening or aging period increased from 30 minutes (6.2) to 24 hours (4.3). The juiciness scores for the halves frozen at 0°F. were lower than the fresh control scores except at the one-hour aging period.

Freezing the halves of chickens at -30°F. had little effect on the juiciness scores for any of the aging periods. The juiciness scores of the halves frozen after aging one-half hour averaged 5.5 compared to 6.1 after six hours of aging and then freezing, and 5.4 after 24 hours of aging.

The pectoralis secundus. The pectoralis secundus was rated less juicy than the pectoralis major. Stewart, Lowe, Harrison and McKeegan (1945) reported similar results for

Table 6. Average palatability scores of the pectoralis secundus muscle of the halves of all the chickens aged various periods of time before cooking or freezing

Time of aging	No. of halves	Aroma	Flavor	Tender-ness	Juici-ness
Fresh control					
30 min.	8	8.9	7.3	3.7	5.5
1 hour	8	8.7	7.6	4.4	4.2
2 hours	8	8.7	8.3	5.1	4.6
6 hours	8	8.7	8.2	7.6	5.0
24 hours	8	8.8	8.1	8.5	3.7
Frozen 0°F.					
30 min.	6	8.9	8.4	8.7	4.4
1 hour	6	8.9	8.2	7.6	4.4
2 hours	6	8.8	8.1	7.2	3.9
6 hours	6	8.9	8.3	8.2	3.5
24 hours	6	8.7	8.1	8.6	3.6
Frozen -30°F.					
30 min.	6	9.0	8.4	8.1	4.3
1 hour	6	8.8	7.8	7.6	4.6
2 hours	6	8.9	7.9	7.6	4.1
6 hours	6	8.9	8.3	8.4	4.4
24 hours	6	8.7	7.8	7.6	3.8

the fowl. The decrease in juiciness scores with aging of the halves of chicken followed a pattern quite similar to that of the pectoralis major.

In general freezing at -30°F. had the least effect on the juiciness scores of both muscles. Also it is interesting that the juiciness scores of the halves of birds frozen at -30°F. were more nearly like the fresh controls than those frozen at 0°F. There is a trend for the higher freezing temperature to increase the dryness of both the pectoralis major and pectoralis secundus muscles. The greatest decrease in juiciness scores for halves of birds frozen at 0°F. was for the groups aged two, six and 24 hours before freezing.

Tenderness

Tenderness of the pectoralis major muscle was determined by two methods, a subjective one, consisting of the ratings of four judges, and an objective measurement of the force in pounds required to shear the muscle. In the case of the pectoralis secundus muscle only the subjective test of judges' scores was used.

After freezing, all halves of roasters and fowl, were defrosted for a 24-hour period in the refrigerator before cooking. Enzymes are not destroyed during freezing. It is possible that part of the tenderizing effect for the frozen halves was due to the action of enzymes during the defrosting

period. All studies in this laboratory indicate the rapid increase in tenderness during aging for the first three hours post mortem. Even when the carcass is chilled rapidly, there is a rapid tenderizing with aging during the first three hours. As the frozen halves of the birds defrosted, an opportunity was offered for tenderizing action by the enzymes. Hence in the following discussion the tenderizing of frozen halves is attributed to the freezing and the defrosting prior to cooking. This treatment is referred to as the freezing-thawing treatment.

Pectoralis major muscle of fresh control halves of chickens. The average tenderness scores for the pectoralis major muscle of the halves of all the chickens are shown in Table 5. The variation in tenderness between roasters and fowl was so great that it seemed advisable to present the mean tenderness scores of roasters and of fowl separately. A comparison of the tenderness of the pectoralis major muscle of the halves of roasters as determined by shear force and tenderness scores is shown in Figure 10.

The average scores for the fresh control roasters aged 30 minutes before cooking was 4.6; the average shearing force was 17.1 pounds. The tenderness decreased at the one-hour aging period, but then increased rapidly with aging to six hours, as is shown graphically by both the scores and the shear force in Figure 10. This rapid increase in

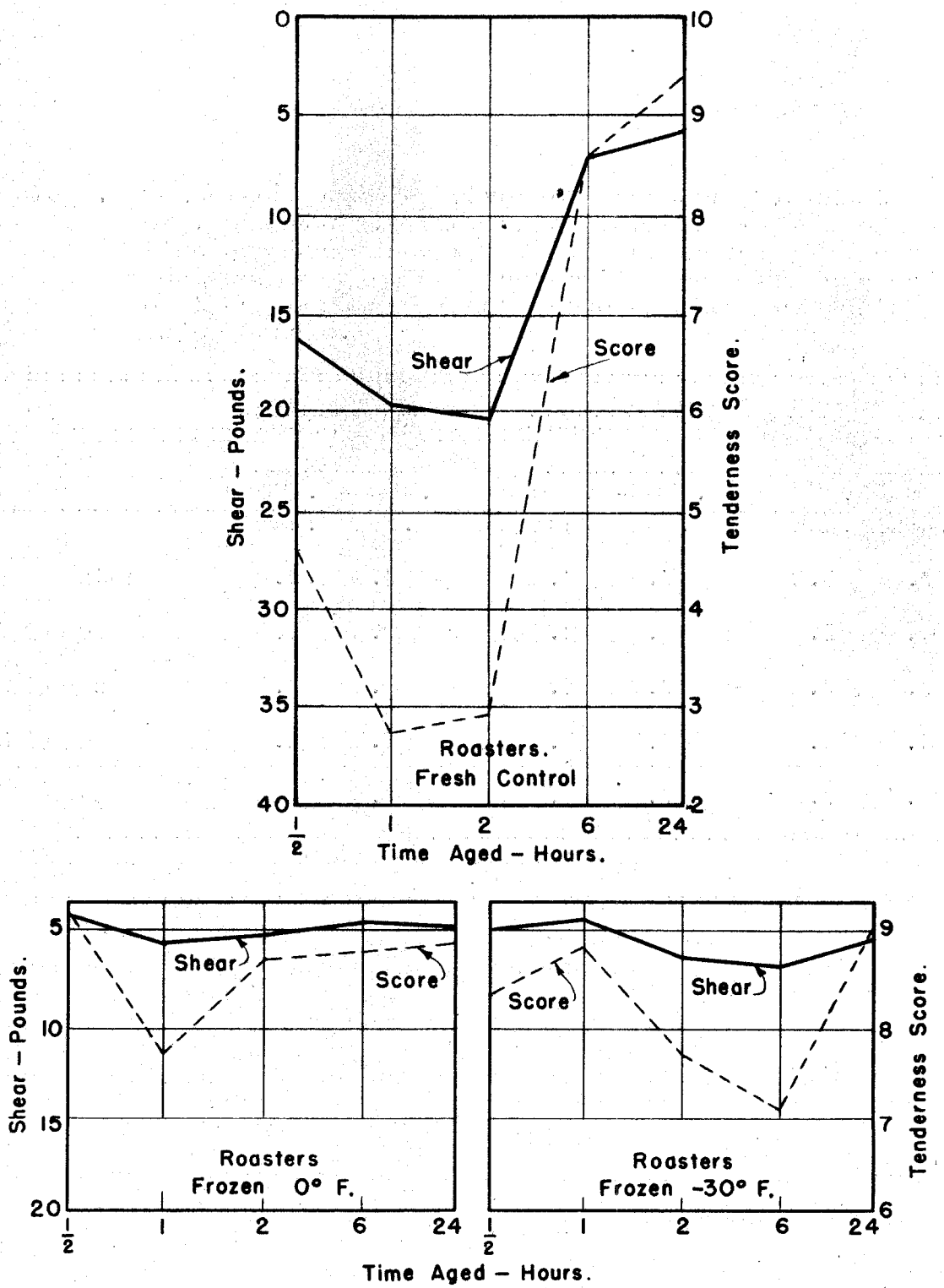


Fig. 10. Average tenderness scores and shear force values for the pectoralis major muscle of fresh control halves of roasters and halves frozen at 0° and -30°F.

tenderness up to a certain aging period and then a gradual leveling off confirms the work of Hanson (1941) on tenderness of broilers, of Stewart, Lowe, Harrison and McKeegan (1945) on fowl and of Lowe et al. (1946) on roasters. Lowe et al. (1946) called attention to the fact that an average score of 8 was reached for the pectoralis major muscle of broilers in three hours, of roasters in 12 hours, and of fowl in 48 hours of aging. In the present study an average score of 8.6 was reached for the pectoralis major or roasters in six hours and for the fowl a score of 8.1 in 24 hours of aging.

The tenderness scores for the fresh control halves of both roasters and fowl follow the shear force curve; see Figures 10 and 11. A study of the data for individual birds in Tables A and B of the Appendix reveals the wide variation from bird to bird in the same aging period. The histological study also shows there is considerable variation between birds aged the same period in the onset and resolution of rigor and the amount of disintegration of the muscle fibers. It is interesting, therefore, that in spite of the variation from bird to bird, there is a consistent increase in the average tenderness scores with increase in aging time.

The tenderness scores for the fresh control halves of fowl follow essentially the same pattern as those for the roasters, the differences being merely of degree. Since the fowl were tougher than the roasters, minus scores were

used. Thus the average tenderness score for the fresh control halves of fowl aged 30 minutes was -2.3; the shearing force was 29.3 pounds. See Figure 11. There was a slight decrease in tenderness at the two-hour aging period. The average shear force for the fresh control halves of fowl aged one hour was 23.9 pounds, with the score 0.5, but the shear force for the two-hour aged group increased to 26.0, with the score 0.4. Stewart, Lowe, Harrison and McKeegan (1945) found a similar decrease in tenderness of fowl after three hours of aging. With the exception of a slight decrease in tenderness at the two-hour aging period, there was a rapid increase in tenderness of the fresh control halves of fowl up to 24 hours of aging. The tenderness score after 24 hours of aging was 8.1, the shear force 7.1 pounds. Stewart, Lowe, Harrison and McKeegan reported a similar score of 8.1 for fowl, but after 48 hours of aging.

Pectoralis major muscle of frozen halves of chickens. The tenderness curves for the halves of roasters frozen at 0°F. and -30°F. present an entirely different picture from that of the controls (Figure 10). There is little variation in tenderness with increase in aging time. A comparison of the curves for the fresh control halves of roasters (upper graph, Figure 10) and those for the halves frozen at 0°F. (lower left graph, Figure 10) shows that after aging 30 minutes the tenderness of the former was rated 4.6, the

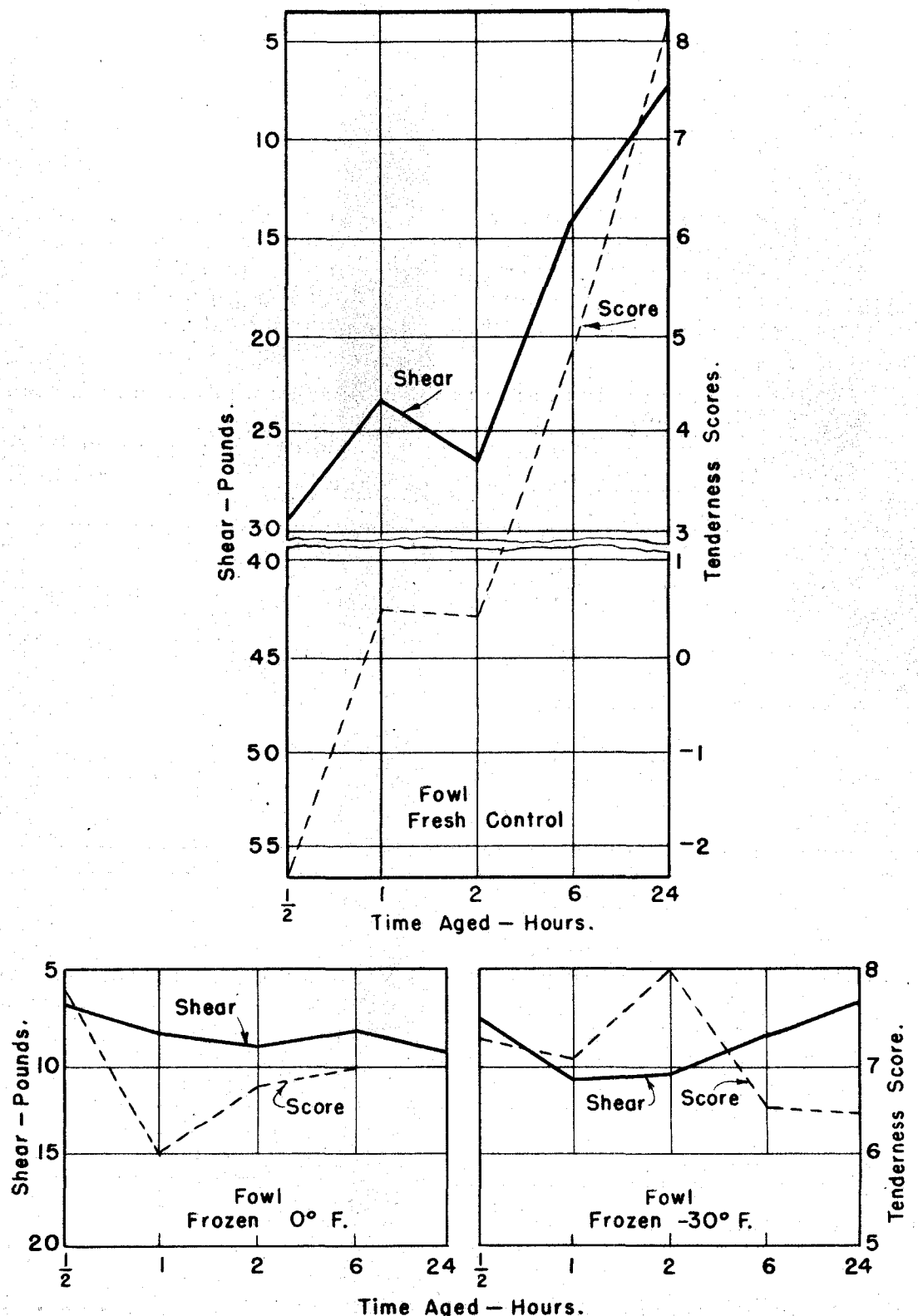


Fig. 11. Average tenderness scores and shear force values for the pectoralis major muscle of fresh control halves of fowl and halves frozen at 0° and -30°F.

latter 9.1, an increase of 4.5 points in tenderness score; the shear force decreased 13.8 pounds. The increase in tenderness in the one- and two-hour aging periods was equally great. For example, at the two-hour aging period the tenderness score for the fresh control halves of roasters was 2.8, for the halves frozen at 0°F., 8.7; an increase of 5.9 points in tenderness score due to the freezing-thawing treatment. At six and 24 hours of aging, however, the increase in tenderness resulting from aging, as indicated by the scores for the fresh control halves (8.6 at six hours and 9.3 at 24 hours of aging) was not further increased by the freezing-thawing treatment (8.8 and 8.9). Apparently the muscle had reached its maximum tenderness before freezing.

The tenderness scores for the halves of roasters frozen at -30°F. followed a pattern similar to that of the halves frozen at 0°F., as shown by the shear force and tenderness scores (lower right graph, Figure 10). At the two- and six-hour aging periods there was a slight decrease in tenderness of the halves frozen at -30°F., but the tenderness increased again in the 24-hour aged group. Since the tenderness scores for the fresh control halves of roasters aged short periods of time were low (4.6, 2.7 and 2.8 for the 30-minute, one-hour and two-hour aging periods respectively) the increase to scores of 8.3, 8.8 and 7.7 for the frozen halves for the same aging periods indicated marked increase in tenderness.

For longer aging periods a similar increase was not found. The average score for the fresh control halves after six hours of aging was 8.6, for the halves frozen at -30°F., 7.1; the fresh control halves aged 24 hours received a score of 9.3, whereas the frozen halves aged 24 hours were rated 9.0.

The freezing-thawing also increased the tenderness of the pectoralis major muscle of the halves of fowl as indicated in Figure 11. The greatest increase was in the group aged 30 minutes then frozen at 0°F., which had a tenderness score of 7.7, an increase of 10 points above the fresh control for the same aging period; the shear force decreased from 29.3 to 7.4 pounds. The fowl aged 30 minutes and frozen at -30°F. showed an increase in tenderness of about the same magnitude with an increase of 9.6 in score and a decrease in shear force from 29.3 to 7.5 pounds. Up to the six-hour aging period, the freezing-thawing treatment increased the tenderness of the halves of fowl frozen at both temperatures above the scores for the paired fresh control halves. The halves of fowl aged 24 hours and then frozen had tenderness scores that were lower (6.4 for 0°F. and 7.0 for -30°F.) than the score of 8.1 for the paired fresh control halves also aged 24 hours. A possible explanation is that the injury to the muscle fibers due to freezing plus the enzyme action during thawing does not tenderize the chicken to the same extent as the disintegration resulting from aging alone.

The effect of aging and aging plus freezing-thawing on the tenderness of the pectoralis muscle of roasters and fowl is presented in a bar graph, Figure 12. An examination of these graphs shows that there is an over-all increase in tenderness due to aging of the fresh control halves of both roasters and fowl. The more tender the chickens the higher the columns representing the judges scores and the lower the shear test value column in Figure 12. Freezing at 0°F. and -30°F. followed by thawing at 39.2°F. (24 hours) definitely increased the tenderness of the halves of all birds over those of the fresh controls except the birds aged 24 hours. In other words, apparently freezing-thawing tenderizes poultry aged short periods of time, but the tenderizing effect diminishes with increased aging up to six hours, and with ripening for 24 hours the effect of aging is as great if not greater.

Pectoralis secundus. The average tenderness scores for the pectoralis secundus muscle of the halves of roasters and fowl aged various periods of time before freezing or cooking are given in Table 7 and shown in the bar graph, Figure 13. The tenderness scores and hence the height of the columns indicate that the pectoralis secundus muscles of the fresh control halves of both fowl and roasters were never so tough as the pectoralis major; see Figure 13. However, the tenderizing of the pectoralis secundus muscle of the fresh

Table 7. The average tenderness scores for the pectoralis secundus muscle of the breast of halves of roasters and fowl aged various periods of time before cooking or freezing.

Time of aging	Fresh control	Frozen at 0°F.	Frozen at -30°F.
30-minute aging			
Roaster	6.4	9.3	9.0
Fowl	1.1	7.7	6.6
Average	3.7	8.7	8.1
1-hour aging			
Roaster	6.1	8.5	8.5
Fowl	3.6	5.8	5.9
Average	4.9	7.6	7.6
2-hour aging			
Roaster	5.8	8.0	8.7
Fowl	4.5	5.7	5.4
Average	5.1	7.2	7.6
6-hour aging			
Roaster	9.0	9.3	8.8
Fowl	6.6	6.4	7.9
Average	7.8	8.2	8.4
24-hour aging			
Roaster	8.8	8.8	7.6
Fowl	8.1	8.3	7.7
Average	8.5	8.6	7.6

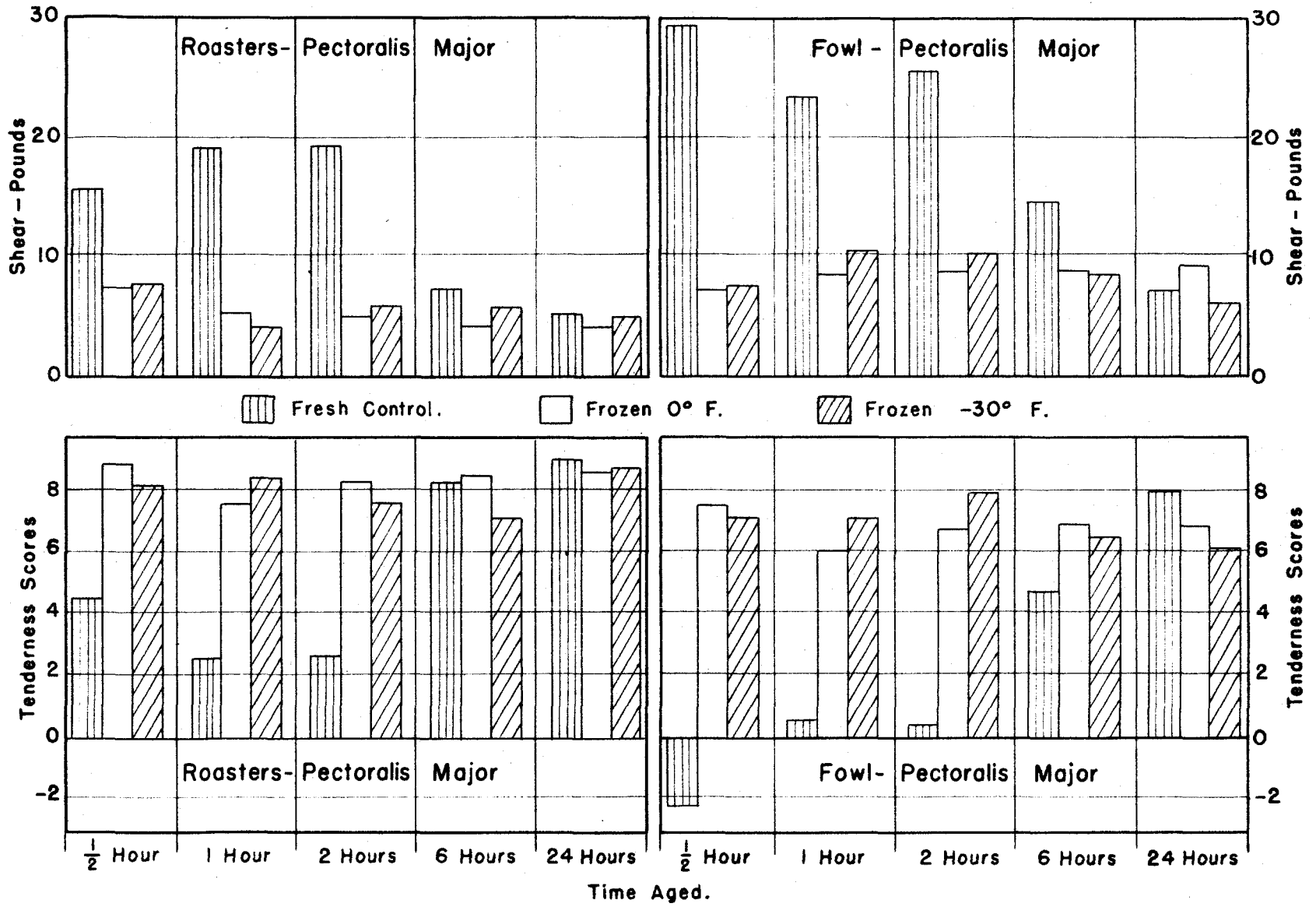


Fig. 12. Tenderness scores and shear force values of the pectoralis major muscle of halves of roasters and fowl.

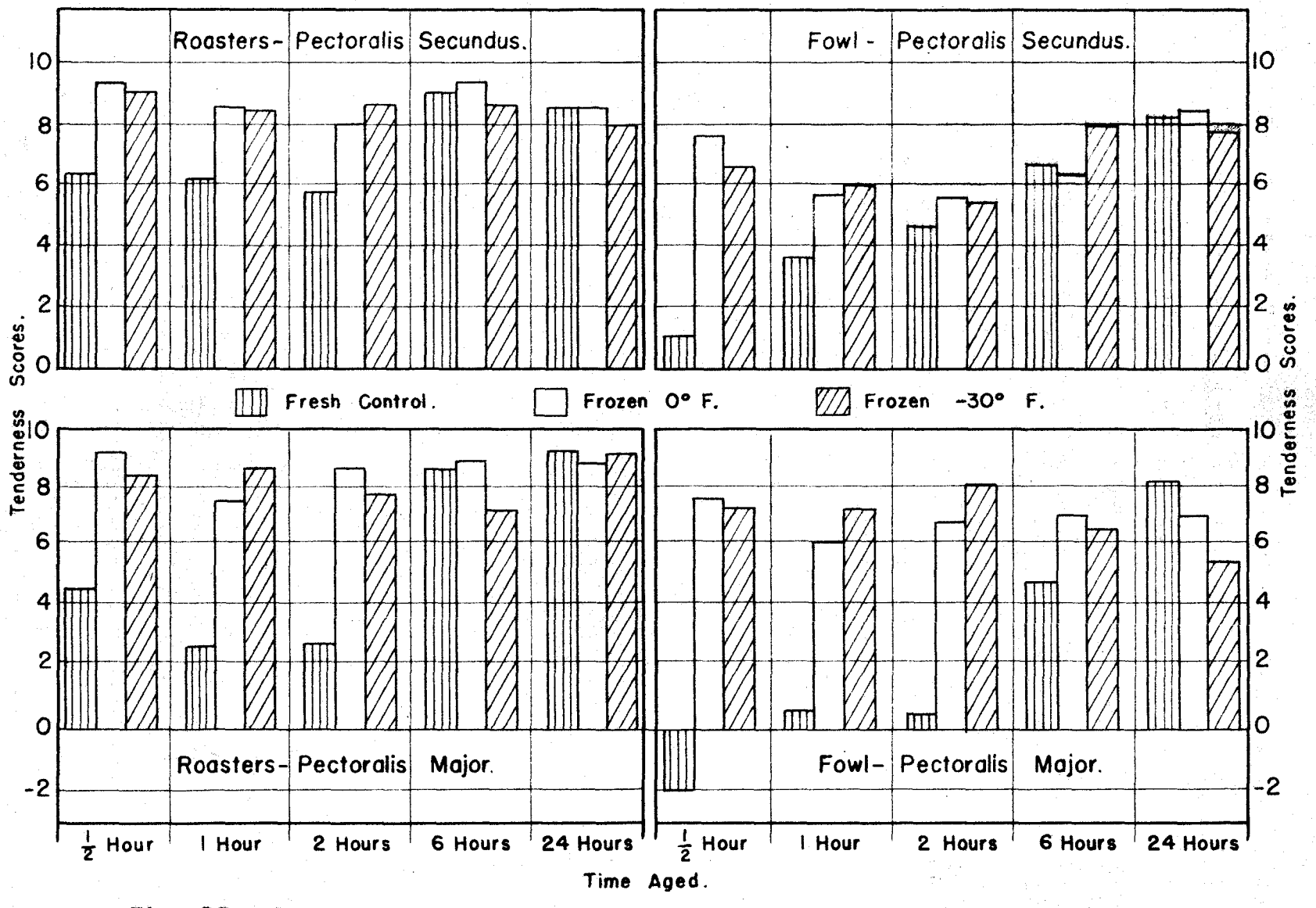


Fig. 13. Tenderness scores of the pectoralis major and the pectoralis secundus muscles of the halves of roasters and fowl.

control halves of both roasters and fowl followed a pattern similar to that of the pectoralis major muscle. The tenderness of the pectoralis secundus muscle of the fresh control halves of fowl showed a rapid increase with aging up to 24 hours, but the roaster halves showed a slight decrease from 30 minutes to two hours of aging and then a large increase in tenderness up to six hours of aging.

Since the average scores for the fresh control halves were higher for the pectoralis secundus than for the pectoralis major, the increase in tenderness due to the freezing-thawing treatment was not quite so startling. However, the effect of the two freezing temperatures and the defrosting prior to cooking on the tenderness of the pectoralis secundus muscle of the frozen halves followed the same pattern as with the pectoralis major muscle. Both muscles show an increase in tenderness due to the freezing-thawing treatment at shorter aging periods, and very little if any increase in tenderness after 24 hours of aging.

The results of the present study indicate that, when birds aged two hours and then frozen are compared with paired halves of fresh controls aged two hours, there is an increase in tenderness due to the freezing-thawing treatment. For example, when the comparison is made between the score of 7.7, for the halves of roasters aged two hours and then frozen at -30°F., and 2.8, the score for the fresh control halves aged a similar period of time, then the effect of freezing-

thawing is very evident. But, if the tenderness score for the pectoralis major muscle of the halves of roasters aged two hours and frozen at -30°F. (7.7) were compared with the score for the fresh control aged 24 hours (9.3), there would be no tenderizing effect.

Stewart, Hanson, Lowe and Austin (1945) reported that the three freezing rates used (-90°, -50° and -5°F.) did not produce detectable differences in the tenderness of broilers held two and 18 hours before freezing, compared to fresh controls aged 24 hours. Wills (1946) reported that fryers eviscerated and frozen within three hours after killing were less tender than similar fryers held 24 to 48 hours before eviscerating and freezing.

An examination of the tenderness scores for individual birds given in Tables A and B in the Appendix shows that there is a wide variation in the amount of tenderizing due to freezing-thawing on the paired halves of birds aged the same length of time. The individual variation between birds shows how important it is to use paired halves in a study on tenderness. Even with this wide variation between birds, the averages of the tenderness scores of the muscles of the frozen halves of the birds aged short periods of time show a highly significant increase in tenderness due to the freezing-thawing treatment. See Table 8.

Table 8. Average tenderness scores and average shear force for the pectoralis major muscle of roasters and fowl aged various periods of time before freezing and cooking.

Time of aging	Fresh control		Frozen at 0°F.		Frozen at -30°F.	
	Shear force	Tenderness score	Shear force	Tenderness score	Shear force	Tenderness score
	lbs.		lbs.		lbs.	
Roasters						
30 min.	17.1	4.6	4.3	9.1	5.0	8.3
1 hr.	19.4	2.7	5.8	7.7	4.8	8.8
2 hrs.	20.5	2.8	5.3	8.7	6.2	7.7
6 hrs.	7.4	8.6	4.6	8.8	6.5	7.1
24 hrs.	5.6	9.3	4.7	8.9	5.5	9.0
Fowl						
30 min.	29.3	-2.3	7.4	7.7	7.5	7.3
1 hr.	23.9	0.5	8.3	6.0	10.9	7.1
2 hrs.	26.0	0.4	8.9	6.8	10.1	8.0
6 hrs.	14.4	4.7	8.3	7.0	8.2	6.6
24 hrs.	7.1	8.1	9.0	7.0	6.7	6.4
Average of roasters and fowl						
30 min.	22.0	1.2	5.9	8.6	6.3	8.0
1 hr.	21.7	1.6	7.1	7.2	7.6	8.2
2 hrs.	23.3	1.6	7.1	8.0	8.2	7.8
6 hrs.	10.9	6.6	6.5	8.2	7.5	7.0
24 hrs.	6.4	8.7	6.9	8.3	6.1	8.2

To determine whether the differences in mean tenderness scores for the pectoralis major muscle of the halves of roasters and fowl were due to the freezing-thawing treatment, freezing temperature or to other factors, such as variation in the birds or variation between judges, an analysis of variance was made.

Table 9. Analysis of variance of tenderness scores of halves of roasters and fowl aged various periods of time before cooking or freezing

Source of variation	Degrees of freedom	Sum of squares	Mean square
Freezing temperature	1	2.81	2.81
Aging	4	775.18	193.80**
Freezing temperature x aging	4	77.88	19.47
Age of birds	1	396.05	396.05**
Freezing temperature x age of birds	1	5.00	5.00
Age of birds x aging	4	44.76	11.19
Freezing temperature x aging x age of birds	4	98.31	24.58
Chickens treated alike (error a)	20	231.50	11.57
Fresh vs. treated	1	1058.51	1058.51**
F[1] x freezing temperature	1	1.02	1.02
F x aging	4	694.55	173.64**
F x freezing temperature x aging	4	60.04	15.01
F x age of birds	1	61.25	61.25*
F x freezing temperature x age	1	12.80	12.80
F x aging x age of birds	4	88.31	22.08
F x freezing temperature x aging x age of birds	4	129.27	32.32
F x chickens treated alike (error b)	20	258.75	12.94

[1]F = fresh vs. treated.

* = significant.

** = highly significant.

The results of this analysis confirmed what has been stated previously. The differences in tenderness scores due to the effect of freezing-thawing were highly significant. The differences in the means of tenderness scores for the halves frozen at 0° and -30°F. were not significant. The differences in tenderness between the roasters and fowl were highly significant. The effect of aging on tenderness was highly significant for the fresh control halves of chicken. These points are illustrated graphically in Figures 10, 11, 12 and 13. When the judges' score means were introduced as an added component, the results of the analysis were the same. There was a variation in the judges' scores, but they were agreed on the factors affecting tenderness. The variation between judges was in the degree or amount of tenderizing.

Effect of cutting the muscle on tenderness. In cutting the birds in half it was necessary to cut the breast muscle on one side of the keel bone. This meant that one half of the bird had no keel bone and a cut breast muscle and the other half had the keel bone and the muscle was intact. The treatment given the cut side was alternated so any effect of cutting would be equalized. In the part of the study in which only one half of the bird was frozen and the other half was used as a fresh control, approximately half of the birds used as fresh controls were the cut sides of the bird and an equal number of cut sides were frozen. To determine the effect of cutting on the tenderness, the tenderness scores

for the cut and uncut sides were averaged separately. It is interesting to note that the average tenderness scores for the cut sides of the birds are generally lower than for the uncut sides for both the fresh controls and the frozen halves. See Table 10.

Table 10. Average tenderness scores for the cut[1] and uncut pectoralis major muscle of the breast of halves of birds. (Cut and uncut sides not from same bird.)

Aging period	Fresh control[2]		Frozen (0°F.)[3]		Frozen (-30°F.)[3]	
	Cut side	Uncut side	Cut side	Uncut side	Cut side	Uncut side
30 min.	-0.1	2.5	7.7	8.5	7.1	8.8
1 hour	0.7	2.3	8.8	7.0[4]	7.6	8.3
2 hours	0.3	2.8	6.9	8.2	7.8	8.4
6 hours	8.0	5.8	7.3	8.3	6.8	7.7
24 hours	8.3	8.8	7.9	8.5[4]	8.4	6.3[4]

[1]The cut side of the bird does not contain the keel bone.

[2]Average of 4 halves of birds.

[3]Average of 2 halves of birds

[4]Only one half of bird.

In the part of the study in which both halves of the birds were frozen, the cut side of the bird was always frozen at -30°F. The tenderness scores for the group of ten roasters in which both sides of the bird were frozen (the cut side at -30°F. and the uncut side at 0°F.) are shown in Table 11.

Table 11. The average tenderness scores for two halves of the same bird, the cut side frozen at -30°F. and the uncut side frozen at 0°F.

Treatment	No. of halves	Aging periods				
		½ hr.	1 hr.	2 hrs.	6 hrs.	24 hrs.
Frozen at 0°F. uncut side*	2	9.7	9.2	9.1	9.4	8.8
Frozen at -30°F. cut side	2	8.1	8.8	7.7	6.3	8.7

*The uncut side contained the keel bone.

The data in Table 11 indicate that the uncut sides of the bird (frozen at 0°F.) are tenderer than the cut sides (frozen at -30°F.). In spite of the fact that an analysis of variance (see Table H in the Appendix) indicates the differences in tenderness scores of halves of cut vs. uncut sides or freezing at 0°F. vs. -30°F. are highly significant, the data are presented only for a record. After further work their validity may be questioned.

There were only two replications for each aging period, and bird variation is great. Through a mistake in plans, the uncut sides were all frozen at 0°F., whereas they should have been frozen at both 0° and -30°F. As has been indicated previously, there was a longer time during the precooling period for autolysis to occur in the halves frozen at 0° than for those frozen at -30°F. How long the halves were defrosted before the end of the 24-hour refrigerator storage

for thawing is not known. Presumably, the halves at -30°F., since they were colder than those at 0°F., would take longer to defrost. The last point to consider is that the effect of cutting of the muscle upon the tenderness of the muscle should decrease with longer aging of the halves. The differences in scores for the uncut and cut sides after one-half, one, two, six and 24 hours of aging are 1.6, 0.6, 1.4, 3.1, and 0.1, respectively. If the one-half and 24-hour aged groups are not included, the difference in scores becomes greater with longer aging.

For freezing one-half hour after killing, the birds were cut in halves 15 minutes after killing. For the remaining aged-groups the division of the bird into halves was one-half hour before freezing. Previous work in this laboratory has indicated that waiting an hour after killing before cutting the breast muscles has little effect upon the tenderness of the cut muscles.

On the other hand, the data (Table 10) from different birds (one-half used as a fresh control and the other half frozen) could be used as an argument that cutting rather than freezing caused the differences in tenderness scores. For this group of halves the difference in tenderness scores was not significant, yet the freezing of the cut side was randomized between 0° and -30°F.

Rate of Freezing

The drop in temperature occurring during the freezing of each of the birds was measured by a recording Leeds and Northrup Micromax. The constantan-copper thermocouple, placed in the thigh of each half of bird before wrapping for freezing, was attached to a set of poles in the room in which the bird was placed for freezing. The poles were connected to the Micromax and the temperature was automatically recorded every six minutes on a moving roll of paper calibrated in degrees Fahrenheit. Freezing curves were made from these detailed data.

There are many factors which affect the time for cooling or the rate of freezing. According to Stiles (1922) such factors as thermal conductivity, specific heat, latent heat, specific surface and the nature of the surface would be included under internal factors which depend on the nature of the cooled product. In this study the initial temperature and weight of the bird were recorded and related to the time required for both precooling and freezing. However, factors such as the shape of the bird, which would affect the surface volume ratio, and the content and distribution of moisture and fat in the carcass cannot be measured with sufficient precision to determine their influence on the cooling rate.

In addition there are a number of other factors which affect the rate of freezing of poultry at any given temperature. The freezing rate may be increased by 1) using packaging materials with low insulating value, 2) preventing air pockets within the package, 3) using methods which accelerate the transfer of heat, such as contact with metal, air blast or immersion in brine, and 4) reducing the size or thickness of the product or removing any excess fat. With these factors in mind, the procedure was standardized to control as many of these factors as possible. Thus, the same packaging material, a pliofilm bag was used for all birds. Before tying the bag, the sides of the bag were pressed against the halves of birds to eliminate air pockets. The birds were cut in half and placed cut side down on a metal shelf in the freezing room, so the heat was absorbed by the metal surface and the air.

With the opportunity for wide variation in all these factors, especially the variation from bird to bird, it is surprising that the curves for individual birds were as much alike as they were. The freezing curves for the individual halves of roasters frozen at 0° and -30°F. for the five aging periods are shown in Figures 14 and 15. The freezing curves for the individual halves of fowl frozen at 0° and -30°F. for the five aging periods are presented in Figures 16 and 17. The temperature was recorded every six minutes by the

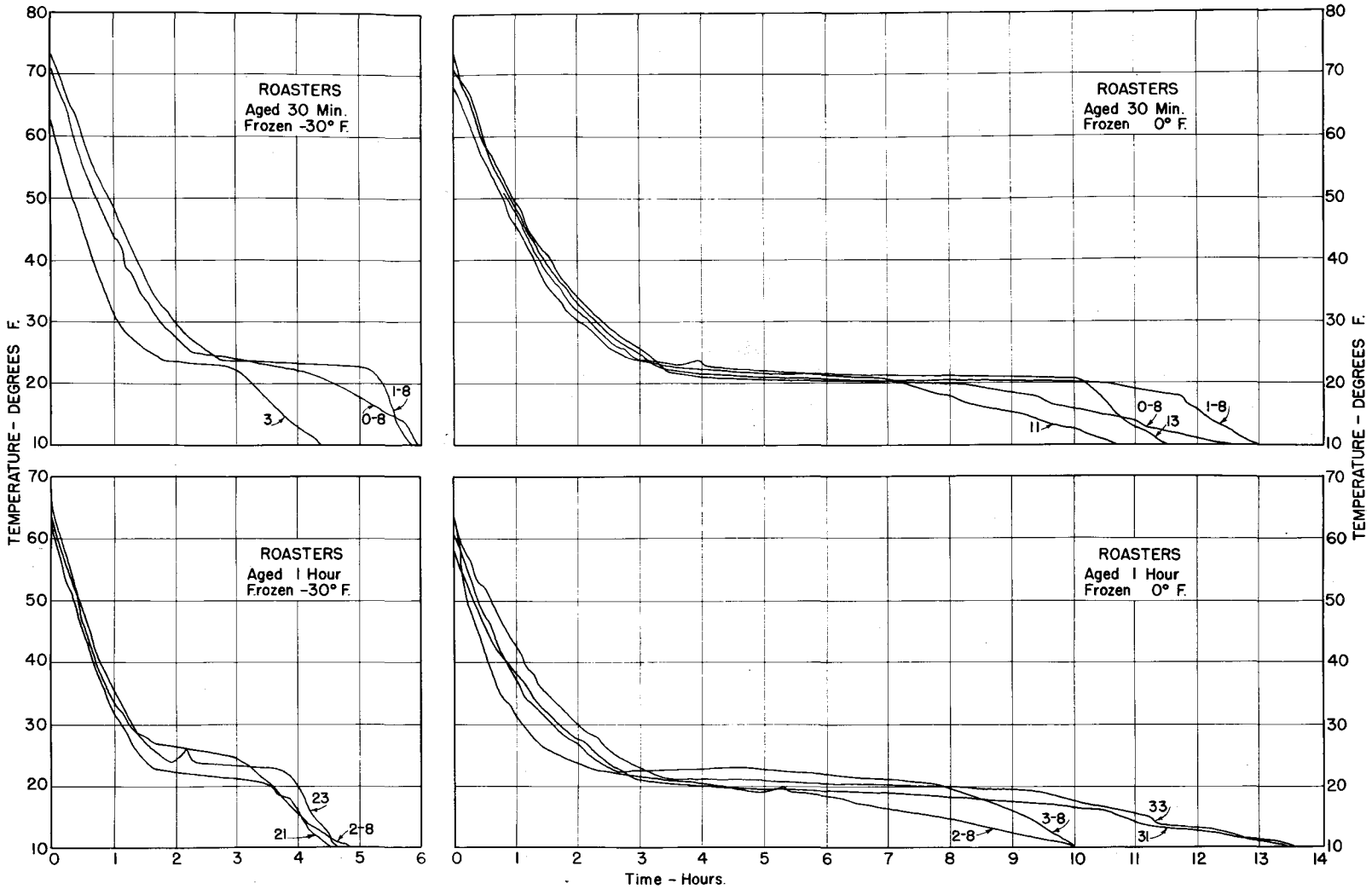


Fig. 14. Freezing curves for individual halves of roasters. (Temperature recorded every six minutes.)

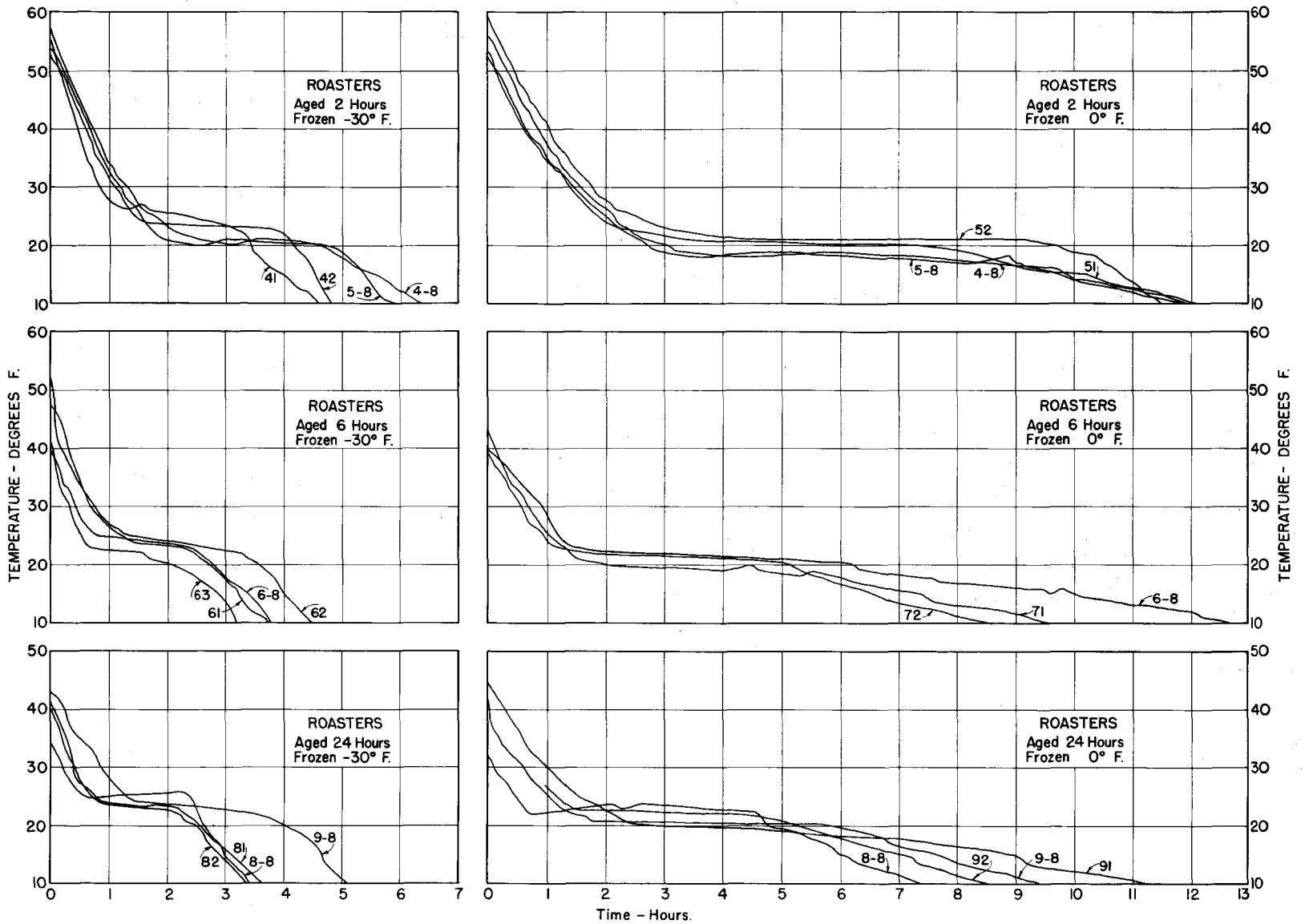


Fig. 15. Freezing curves for individual halves of roasters. (Temperature recorded every six minutes.)

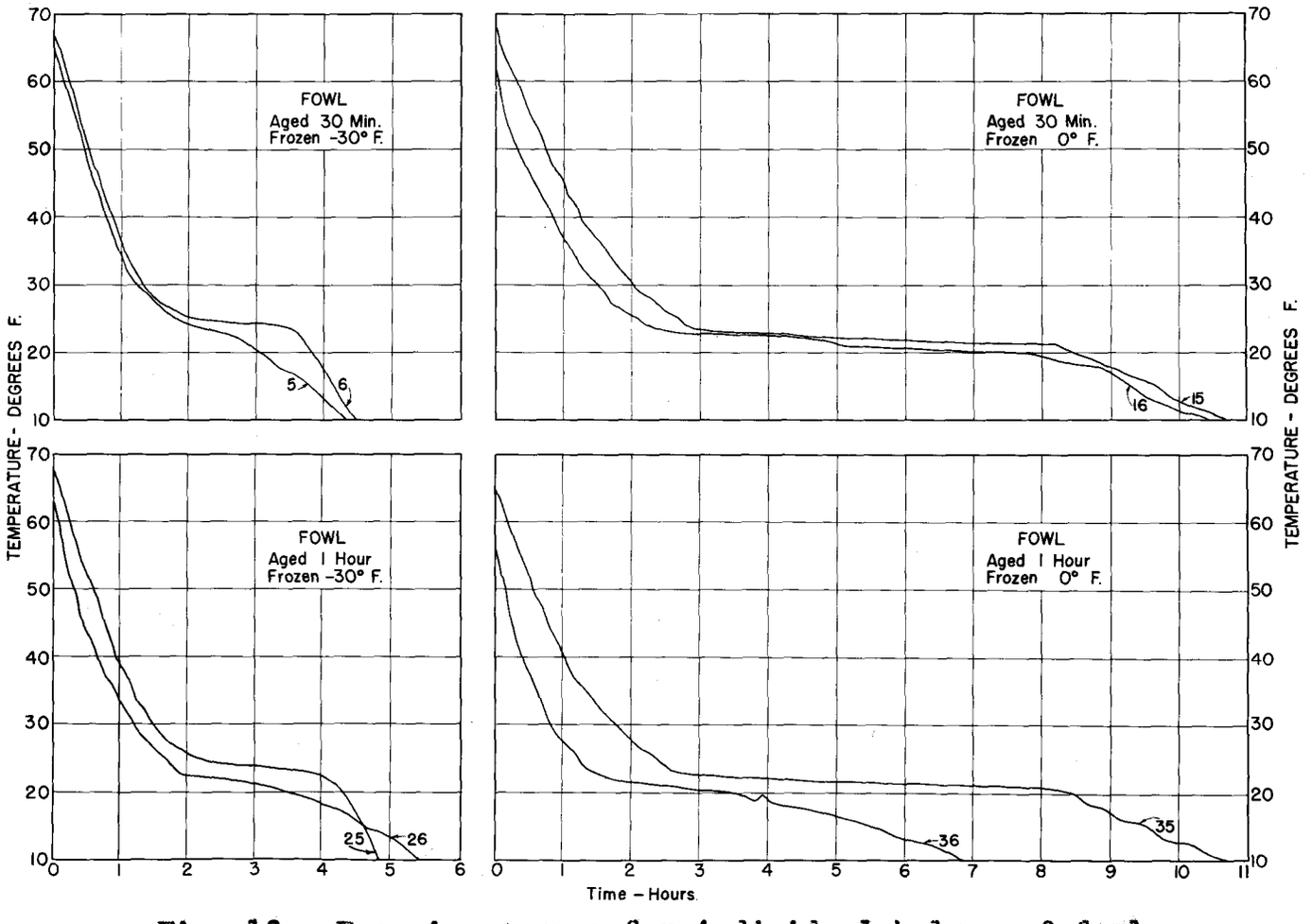


Fig. 16. Freezing curves for individual halves of fowl. (Temperature recorded every six minutes.)

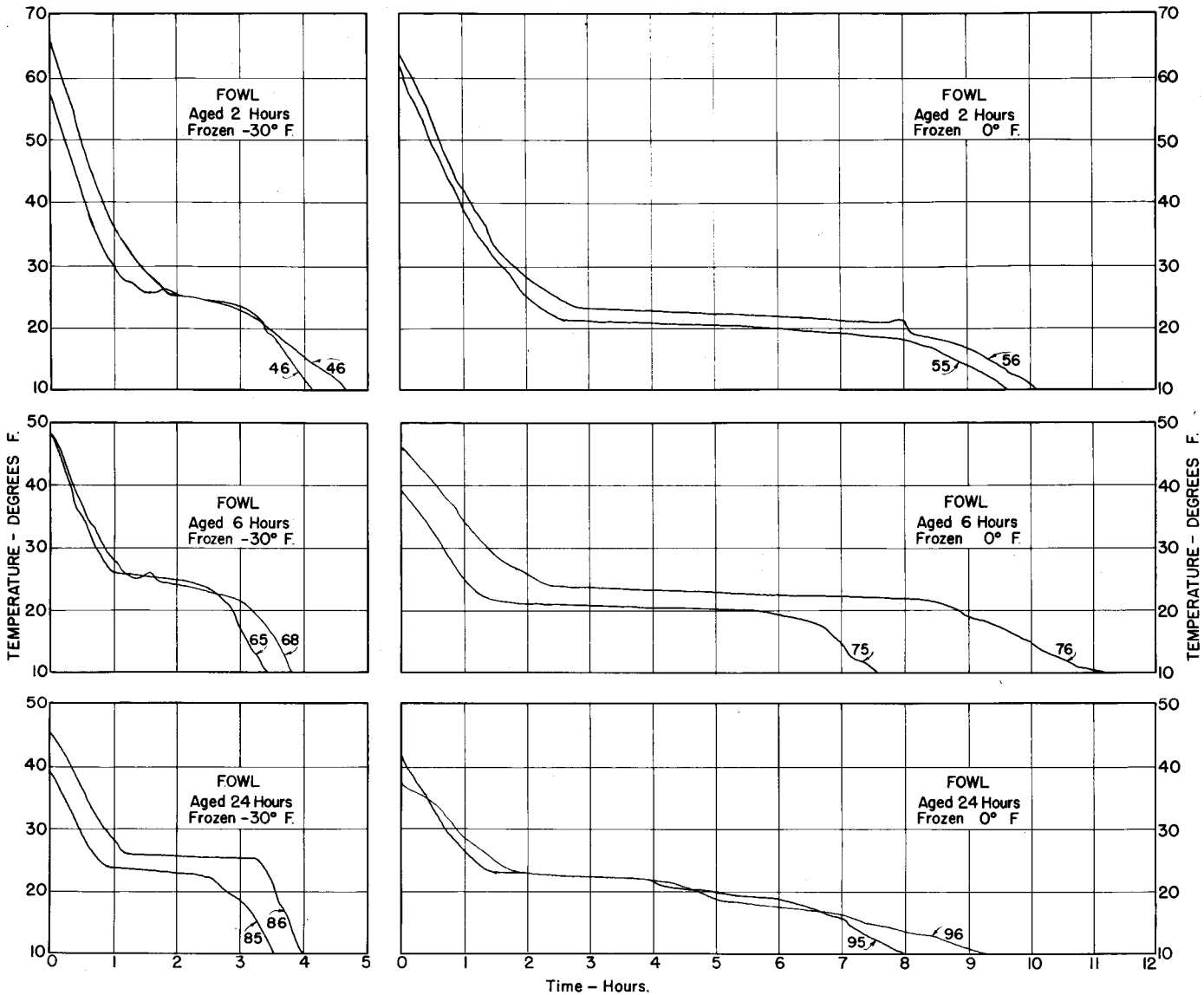


Fig. 17. Freezing curves for individual halves of fowl. (Temperature recorded every six minutes.)

Micromax and the curves were made using all the points. The striking thing about these curves is the similarity between the freezing curves for the halves of different birds aged the same length of time and frozen at the same temperature, especially considering the large number of uncontrollable factors. Another outstanding feature is the difference between the curves for the two freezing temperatures at the same aging period. Obviously the birds frozen at 0°F. took longer to reach 10°F. than the birds frozen at -30°F. The thermal arrest (flat part of the curve) is longer for the higher freezing temperature. Also there is an interesting difference in the thermal arrest in the freezing curves of birds frozen at the same temperature but aged different lengths of time. Chickens aged six and 24 hours required less time to freeze than those aged 30 minutes, one hour and two hours.

Average curves for all birds aged the same period of time and frozen at the same temperature were constructed by calculating the average temperature for the birds receiving the same aging and freezing treatment at 12-minute intervals. The freezing curves for the halves of chickens frozen at -30°F. are shown in Figure 18. There is a noticeable difference between the chickens aged 30 minutes, one hour and two hours, and those aged six and 24 hours and frozen at -30°F. The freezing curves for the halves of chickens frozen at 0°F. after aging various periods of time are shown in Figure 19.

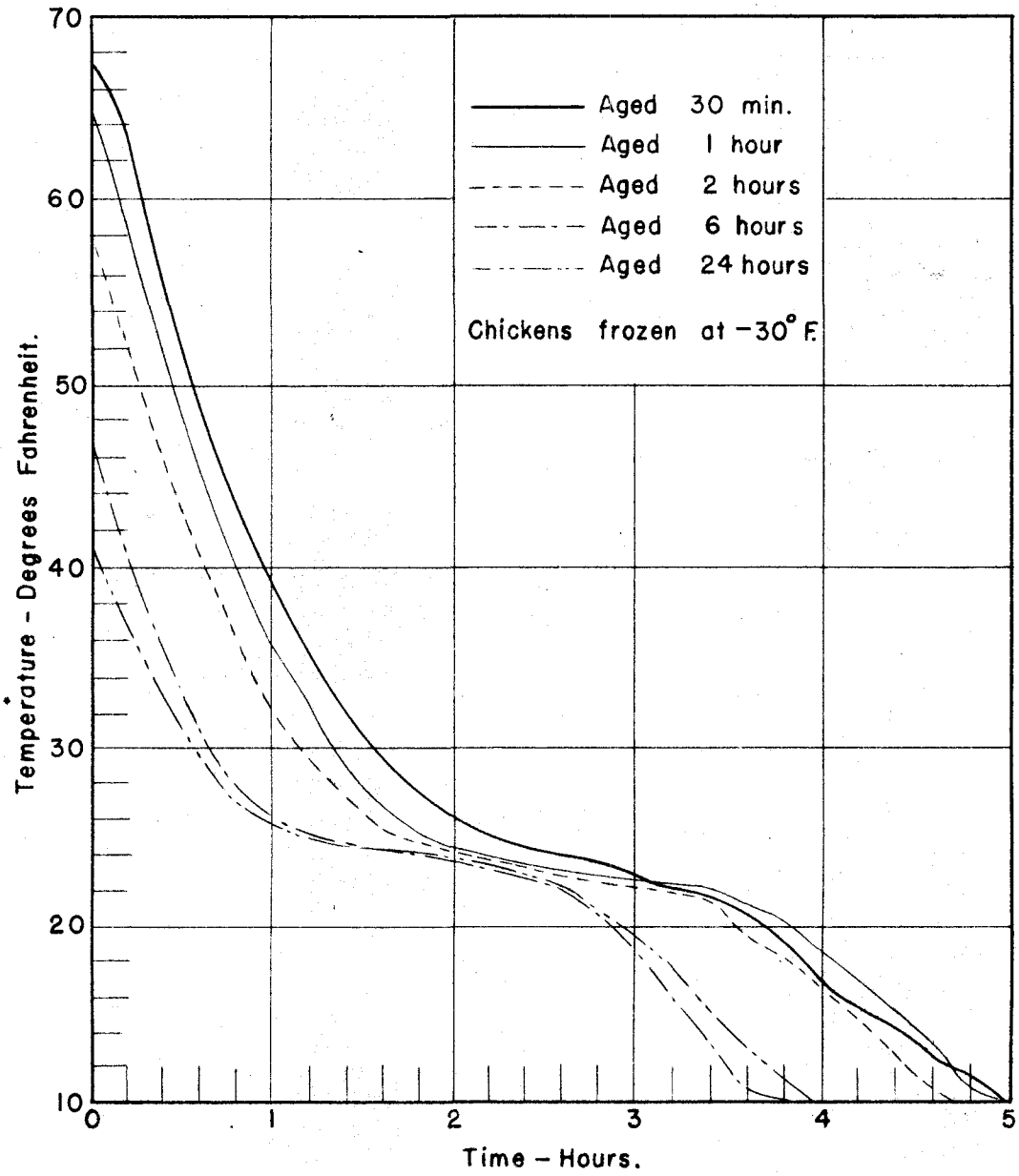


Fig. 18. The average freezing curves for chickens frozen at -30°F.

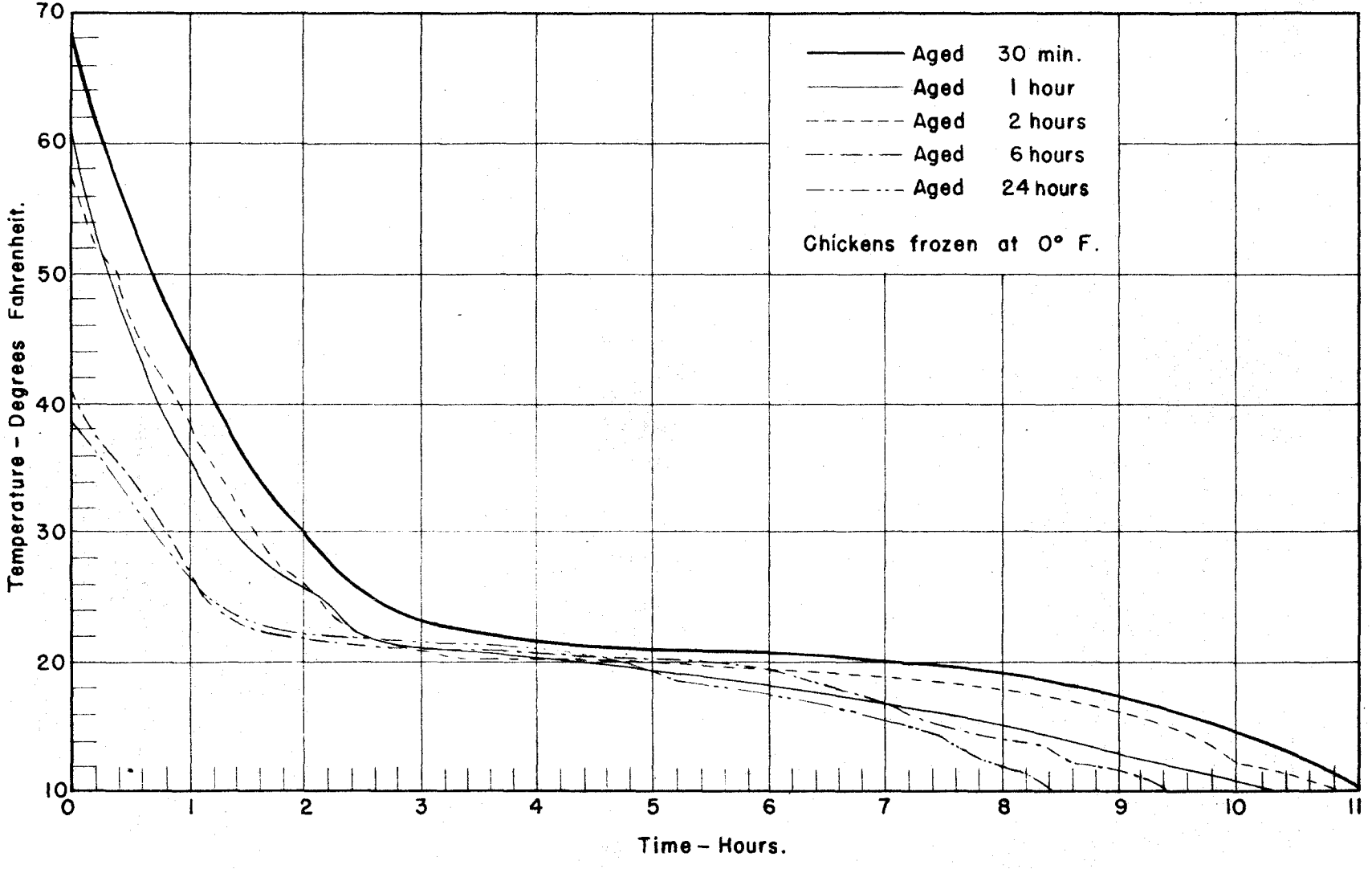


Fig. 19. The average freezing curves for chickens frozen at 0°F.

The data for the halves of roasters and fowl frozen at -30°F. after aging for various periods of time are presented in Table 12; similar data for the halves frozen at 0°F. after the five aging periods are shown in Table 13. These data bring out some very interesting facts and emphasize the effect of weight, initial temperature, and aging on the total cooling time. An examination of the initial temperature and the cooling period shows that as the initial temperature decreases the time required for cooling decreases. This is to be expected.

A comparison of the average time required for the temperature to drop from 28° to 10°F. for both the roasters and fowl for all aging periods reveals that the fowl frozen at -30° and 0°F. took less time than the roasters. As noted before, the fowl weighed less than the roasters, which would explain the shorter cooling time although other factors probably would influence it.

Another comparison is between the time of freezing at the two temperatures. This information was calculated on the basis of the average time required by all the birds to drop from 28° to 10°F. at each temperature. An average of approximately three hours, 24 minutes, was required to cool from 28° to 0°F. for all the halves of chicken frozen at -30°F. This would be a cooling rate of approximately 5.5°F. per hour. In the case of the chickens frozen at 0°F., it

Table 12. Freezing data for halves of roasters and fowl frozen at -30°F. after various periods of aging before freezing

Aging period	Weight	Initial temp.	Cooling period initial temp. to 28°F.		Time from initial temp. to 10°F.		Time from 28°F. to 10°F.	
	gms.	°F.	hrs.	min.	hrs.	min.	hrs.	min.
30 minutes								
Roasters	954.0	69	1	54	5	36	3	42
Fowl	593.0	67	1	30	4	30	3	00
Average	833.6	68	1	42	5	3	3	21
1 hour								
Roasters	817.8	65	1	24	4	42	3	18
Fowl	745.0	66	1	30	5	00	3	30
Average	793.5	65.5	1	27	4	51	3	24
2 hours								
Roasters	822.3	55	1	18	5	18	4	00
Fowl	793.5	61	1	24	4	18	2	54
Average	812.7	58	1	21	4	48	3	27
6 hours								
Roasters	912.8	45		42	3	42	3	00
Fowl	543.0	48		54	3	30	2	36
Average	789.5	46.5		48	3	36	2	48
24 hours								
Roasters	887.5	40		36	4	00	3	24
Fowl	615.5	42		42	3	54	3	12
Average	796.8	41		39	3	57	3	18

Table 13. Freezing data for halves of roasters and fowl frozen at 0°F. after various periods of aging before freezing

Aging period	Weight	Initial temp.	Cooling period initial temp. to 28°F.		Time from initial temp. to 10°F.		Time from 28°F. to 10°F.	
	gms.	°F.	hrs.	min.	hrs.	min.	hrs.	min.
30 minutes								
Roasters	904.0	71	2	30	12	00	9	30
Fowl	659.0	65	2	00	10	36	8	36
Average	822.3	68	2	15	11	18	9	3
1 hour								
Roasters	968.5	62	1	48	11	24	9	36
Fowl	620.0	61	1	30	9	00	7	30
Average	852.3	61.5	1	39	10	12	8	33
2 hours								
Roasters	983.3	55	1	30	11	48	10	18
Fowl	626.0	62	1	42	9	48	8	6
Average	857.5	58.5	1	36	10	48	9	12
6 hours								
Roasters	922.3	41		54	10	00	9	6
Fowl	576.5	42	1	6	9	24	8	18
Average	807.0	41.5	1	00	9	42	8	42
24 hours								
Roasters	951.3	40		48	9	12	8	24
Fowl	701.5	39		54	8	12	7	18
Average	868.0	39.5		51	8	42	7	51

took eight hours and 40 minutes for the temperature to drop from 28° to 10°F. This would be an average cooling rate of approximately 2.1°F. per hour, or less than one-half the rate at -30°F. Although the data are not comparable, it is interesting to note that Brady et al. (1942) reported a cooling rate of 5.3°F. for steaks 0.6 inch in thickness frozen at 0°F. and a cooling rate of 2.5°F. for steaks frozen at -15°F.

Quick vs. fast freezing

The terms fast freezing and slow freezing have been used vaguely and have no definite meaning. Moran (1932) states that meat is quick frozen if it is chilled through the temperature range of 41° to 23°F. in one-half hour or less. The range of 41° to 23°F. was chosen because at the latter temperature 82 per cent of the water in muscle is frozen. Quick freezing is defined by Poole (1935) as freezing by any method in which the meat is chilled through the temperature range 31° to 25°F. in 25 minutes. He states that in 1925 Plank reported that between the temperatures of 31° and 25°F. approximately 75 per cent of the total water content is frozen, and this temperature range was termed "the zone of maximum crystal formation." In the zone of crystal formation the latent heat which must be absorbed from a given area of meat during the solidifying of most of the liquids is greater

than at any other time in the freezing; hence the curve tends to flatten out, especially in slow freezing. Probably in this zone the large crystals may be formed; hence if the poultry passes through the crystal-formation zone rapidly, the ice crystals formed may be less destructive. For beef the zone of crystal formation is from 31° to 25°F. The data obtained in this study indicate that this "zone of maximum crystal formation" is lower for poultry, from 26° to 20°F. approximately.

Studies have shown that each food product has its own typical freezing curve. Many factors may influence the time required for freezing. Short and Bartlett (1944) have published some interesting results of a study on the specific heat of foodstuffs. Of the 18 foodstuffs studied, they report that the initial freezing point may vary from 24.3° for grapes to 31.6° for eggs, whereas complete freezing occurs between -20 and -40°F. Other factors than the per cent of water determine the initial freezing point. For example, beef with 71.5 per cent water has the same initial freezing point of 31.3°F. as fresh ham with 52 per cent water. They also point out that in the frozen region, the sugar or salt or starch content of the substance has an appreciable effect on the freezing range and hence will cause a large variation in the region between the initial and final freezing points of the substances. In the present study the data indicate that

the initial freezing point for chicken is 23.5°F.

DuBois, Tressler and Fenton (1942) in a study of the effect of the rate of freezing on the quality of frozen poultry show curves indicating the rates of drop in temperature taken in the thigh of five-pound roasting chickens in air blast and still air at different temperatures and in Birdseye plate froster. They report a total time of approximately four hours required for the temperature to drop from the initial temperature 55° to 10°F. when frozen by the double contact method in a Birdseye multiplate froster; approximately 10 hours was required for the same temperature drop when the chickens were frozen at 25°F. in still air. In the present study, four hours and 40 minutes were required for a similar drop in temperature (55° to 10°F.) for halves of chickens frozen at -30°F. in still air in contact with a metal shelf, and 10 hours and five minutes for those frozen at 0°F. The variation between the two studies can be accounted for in part by the difference in the size of the frozen product, whole birds vs. halves of birds. However, other factors mentioned previously would affect the rate of freezing as well as the freezing temperature. This would help to eliminate some of the confusion that now exists in the literature between the effects of slow and fast freezing.

Thawing

Any study on the effect of freezing on tissues of

necessity includes thawing if the final results are judged on the cooked product. The rate of thawing can be varied by varying the temperature at which the food is thawed, which would in turn vary the length of time required for defrosting and hence the period during which enzyme activity could occur. In this study the thawing was accomplished at 39.2°F. (4°C.) for a period of 24 hours. Some enzyme action would occur but much less than at higher temperatures. Smorodintsev and Nikolaeva (1945) reported that in cow muscle incubated for 24 hours the peptidase activity was increased 25 per cent at 37.4°F. and 140 per cent at 98.6°F.

Defrosting poultry in the oven would increase the rate of thawing, but would it affect the tenderness of birds frozen only 24 hours? This might be an interesting sequel to this study. To test this in a preliminary fashion, one bird was cut in half and both sides were frozen. After 24 hours one half was cooked and the other half defrosted in the refrigerator for 24 hours and then cooked. Of course, no conclusions can be drawn, but it is interesting to note that the half defrosted in the oven was rated 8.0 in tenderness by the judges' scores and required 5.8 pounds shear force, whereas the half defrosted in the refrigerator was rated 9.5 for tenderness score and needed 6.3 pounds shear force. In this instance the judges scores and the shear force values did not correlate. Hoffert (1947) studied the

effects of defrosting methods on paired halves of frozen and stored roasters. She reported that the defrosting treatments, thawing at room temperature, in the oven and in the refrigerator did not appreciably affect the palatability scores.

Histological Studies

Histological samples

Samples for the histological studies of the pectoralis major muscle of each half of bird were obtained as follows: 1) from the fresh half of the bird to be cooked and from the half to be frozen, 2) from the cooked fresh control half, 3) from the frozen uncooked half of bird, and 4) from the frozen-thawed half of bird after cooking. After the birds were cut in half, a small sample of tissue was removed from the pectoralis major muscle about one inch anterior to the sternal crest of both halves of the bird. The sample from the frozen half was sawed out immediately after removing the chicken from the freezer. The tissue was taken from a spot corresponding as near as possible to the place from which the sample had been removed from the other half of the bird used as a fresh control. After cooking, a sample was obtained from each half about one inch posterior to the cut made by removing a sample from the uncooked muscle. All samples were immediately placed in the fixing solution. This meant that the frozen sample thawed in the fixing solution.

Descriptive terms used

Some of the descriptive terms used originated in the foods research laboratory at Iowa State College; others are found in the literature.

Turbulence as used by Carey (1940) denotes a disturbance of the cross striae caused by a violent shock and is characterized by a disorganization of the striae.

Rigor nodes is a familiar term found in the literature to describe a contraction of a muscle in rigor. In the contracted part of the node the fiber bulges and the cross striae are exceedingly close together. In strong contraction, nodes are greatly compressed with homogeneous cytoplasm. The length of the contracted area varies. On each side of the contracted area is a rarefied area in which the cross striae are much wider than usual or sometimes are thrown out of alignment. Often the fiber is narrow in this area.

Rigor ridges is a term used to describe a very narrow area in which the cross striae are condensed. Only a few cross striations form the rigor ridges instead of many, as in the rigor nodes. In some of the birds the rigor ridges often cover all the fibers forming an interesting rhythmic pattern. The edges of the ridges are often curved and occur rather close together with prominent longitudinal or turbulent striae between them.

The term waves is self-explanatory; however, the

character of the waves differs. Sometimes they are deep, sometimes shallow, long smooth and rolling, or they may be angular at the bend, short and rather closely packed. Fibers in the waves may have kinks and twists. Often all the fibers in a certain area may be involved in the waves or the wavy pattern may be repeated along a fiber for some distance.

Disintegration is the term applied to loss of the characteristic structure of muscle fiber protoplasm, in which the longitudinal and cross striations are replaced by granular material. If the sarcolemma is not broken, the granular substance remains within the fiber. Such a fiber exhibits a segmental arrangement of granular substance alternating with normal protoplasm with striations. Sometimes the sarcolemma is broken and some or all of the granular material may have exuded, leaving clear spaces in the fiber.

Vacuoles is the term used to denote the small cavities or spaces in the muscle fiber which are assumed to indicate the spaces formerly occupied by the ice crystals. Indentation is the term applied to the small depressions or notches along the sides of the muscle fibers which are presumed to result from the pressure of ice crystals between the fibers.

Differences between frozen and unfrozen tissues

Aside from injury to the muscle tissues by formation of ice crystals, which will be discussed later, the frozen

muscle fibers were usually better differentiated and the cross striae more evident than in the unfrozen muscle. The characteristics of the cooked unfrozen tissue are shown in the lower picture, Figure 20. Note the prominence of the longitudinal striae and the small amount of granular material along the edges of the fibers at the top and bottom of the picture. The frozen cooked tissue shows the vacuoles in the fibers filled with granular material and the rather prominent cross striations (upper picture, Figure 20).

Differences between uncooked and cooked frozen tissues

The sections of cooked muscle were cut 15 microns thick and the uncooked were 25 microns thick; however, the cooked sections were more opaque, appeared thicker and were less friable than the uncooked sections. The fibers, striations and vacuoles of the cooked frozen tissues differed in appearance from those of the raw frozen ones. In addition, the cooked tissues were characterized by large amounts of granular material. In general, the uncooked tissues had more waves, kinks and twists than the cooked tissues. This generalization does not imply that waves, kinks and twists were never found in the cooked tissues. Some cooked tissues were very wavy, but the reverse was true in a majority of the cases. Cooked fibers were usually, but not always, better differentiated than the uncooked ones. Also the

Fig. 20, Upper picture. Cooked pectoralis major muscle. Frozen at -30°F., 1-hour roaster 21L. (Magnification, 675x)

Showing the vacuoles in the fibers filled with granular material and the rather prominent cross striations.

Fig. 20, Lower picture. Cooked pectoralis major muscle. Fresh control, 1-hour roaster 21R. (Magnification, 560x)

Note the prominence of the longitudinal striae and the small amount of granular material along the edges of the fibers at the top and bottom of the picture.

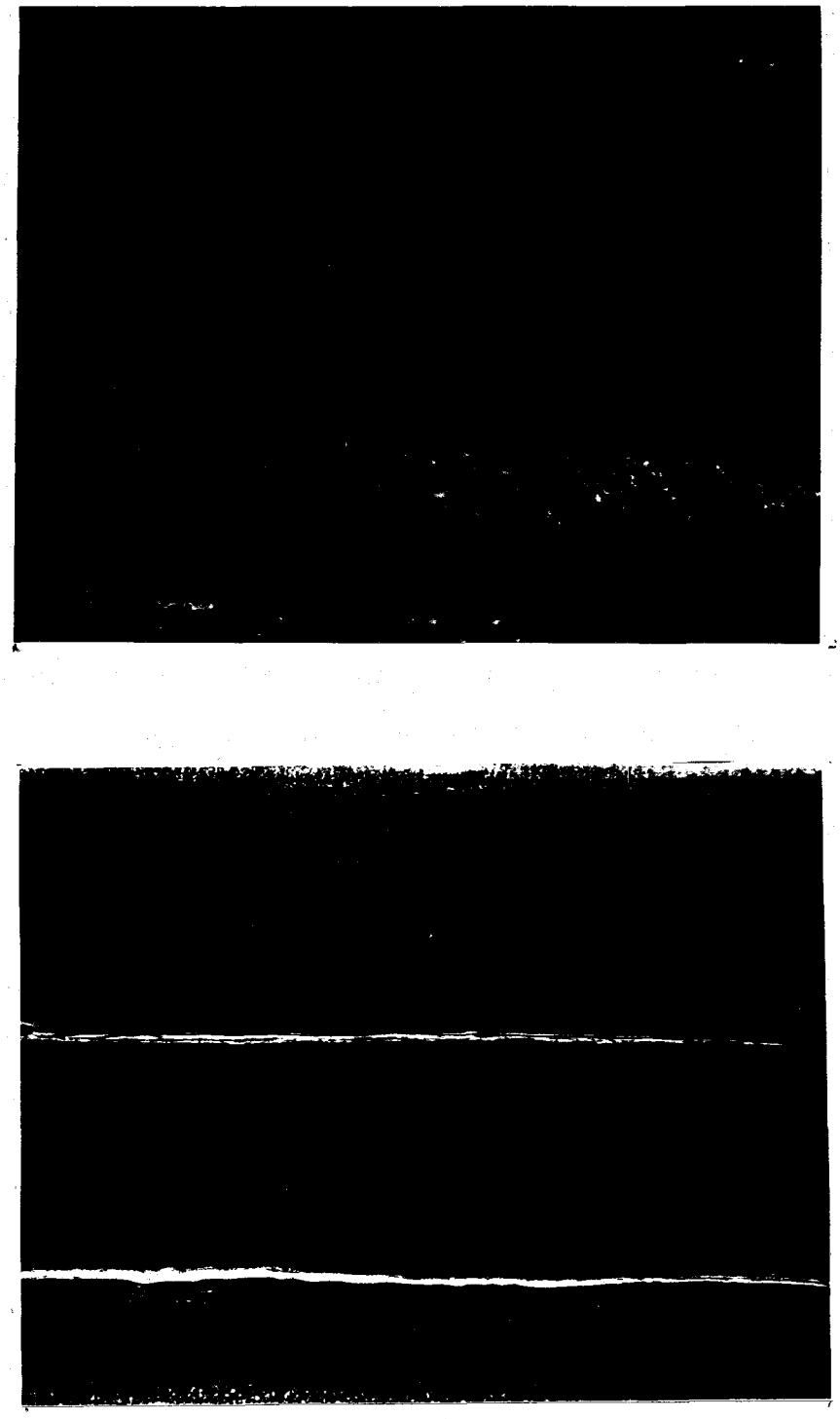


Figure 20.

striations, cross and/or long ones, were frequently more distinct in the cooked tissues.

Granular material. The granular material (with a polka dot appearance) was found in the sections of the cooked tissues. Granular material was found also in the vacuoles of the cooked fibers. It was found between some fibers and adjoining indentations in the edges of some fibers. It was usually more concentrated over or near the connective tissues. If the source of the granular material was gelatin, its distribution in most areas is explained by the penetration of the muscle fluids containing gelatin into the crevices. The amount of granular material varied in the sections from different birds. Sometimes the amount was so great that it hindered observations of the details of the tissues; sometimes very little granular material was present.

Source of the granular material. Because of the distribution of the granular material in the sections and its occurrence in the cooked, but not in the uncooked sections, the logical explanation of its source is gelatin. It is known that the muscle fluids contain gelatin. When the muscles were cut for scoring, the fluids oozing from the muscles would gel upon cooling.

The amount of collagen transformed to gelatin would vary with several factors, and this could account for the varying amounts of granular material in sections from different birds.

The amount of collagen transformed to gelatin varies, not only with the temperature to which the collagenous tissues are heated (90.5°C. for interior of thigh), but also with the time held at a given temperature. The amount of gelatin produced would vary also with the pH of the muscle tissues and with the kind and concentrations of salts present. It is interesting to note that a direct relationship existed between cooking time and the amount of granular material. The amount of granular material was greater in birds in which the cooking time was prolonged owing to a flattening of the curve for the interior thigh temperature before 195°F. (90.5°C.) was reached.

If the sarcolemma remained intact and gelatin was the only source of the granular material, then the gelatin would have to penetrate into the fiber in order to be found in the vacuoles. This penetration of the gelatin could be easily accomplished if the fiber wall is broken, but less readily otherwise. The liquid from the melted ice crystals must contain some of the plasma proteins. The albumins and globulins would be coagulated on heating and thus might be a source of the granular material. See Figure 21 for granular material in a vacuole. Note that the vacuole stops at the kink in the fiber.

The extent of aging before freezing also seemed to affect the amount of granular material found in the sections. This will be discussed later.

Fig. 21. Cooked pectoralis major muscle. Frozen at -30°F., 30-minute fowl 5L. (Magnification, 675x)

Note the vacuole stops at the kink in the fiber and also the granular material in the vacuole.

Figure 21.

several smaller ice crystals. Fibers from birds frozen at -17.8°C. (0°F.) had larger ice crystals which were located outside and between the fibers, inter-fibrillar freezing. In intra-fibrillar freezing the ice columns formed parallel to the long axis of the fiber. The fiber protoplasm was displaced to the sides of the fiber so it surrounded the ice column.

However, the procedure used in the preliminary investigation was not followed in the experimental study and the evidence of the location of the ice crystals is based upon observation of the histological longitudinal sections with a few cross sections from frozen-thawed and frozen-thawed-cooked muscles. The criteria for the location of the ice crystals are the vacuoles and the visible injuries to the fibers which remain in the thawed tissues. To be valid criteria, the evidence of the location of ice crystals should not be found in unfrozen tissues. Vacuoles were the best evidence of intra-fibrillar freezing and were not found in the unfrozen sections.

Vacuoles. Vacuoles were observed in the fibers of cross sections (Figure 22) and in longitudinal sections (Figures 21 and 23). Note the lack of granular material in the columnar vacuole of Figure 23. Usually the vacuoles were columnar in shape; sometimes they were bead-like or lenticular in shape (Figure 24). As shown in Figure 24, it

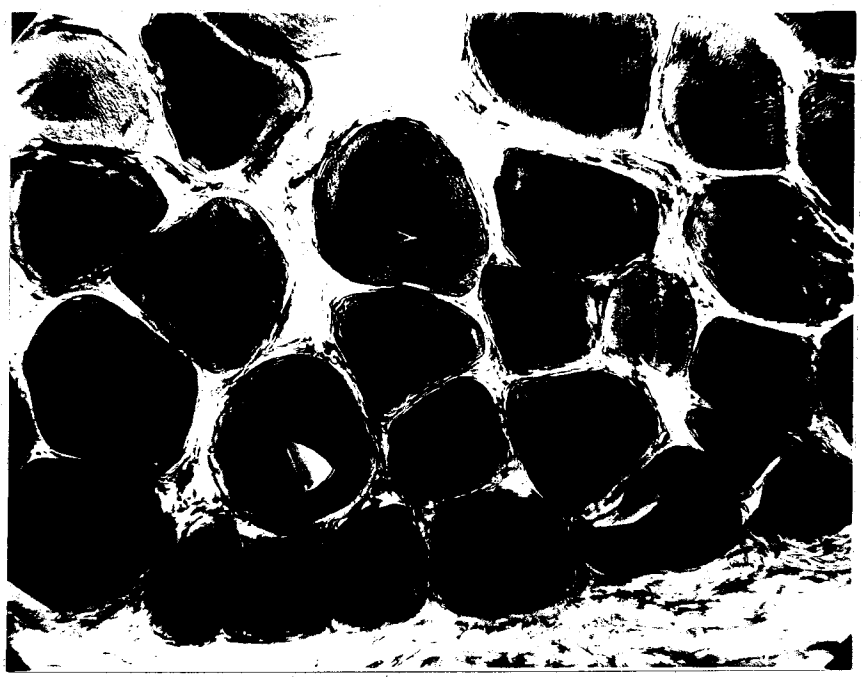


Fig. 22. Uncooked pectoralis major muscle. Frozen at 0°F., 30-minute roaster 1-8L. (Magnification, 225x)

Showing location of vacuoles in the fibers.

Fig. 23. Uncooked pectoralis major muscle. Frozen at -30°F., 30-minute fowl 5L. (Magnification, 675x)

Showing vacuole in an uncooked frozen-thawed fiber. Note the lack of granular material in the columnar vacuole and the manner in which the myofibrils have been pushed against the sides of the fiber. The cross striae are very distinct.

Figure 23.

Fig. 24. Cooked pectoralis major muscle. Frozen at -30°F., 30-minute roaster 0-8L. (Magnification, 675x)

Showing the bead-like and lenticular-shaped vacuoles. Note the polka dot appearance of the granular material and the prominence of the cross striae. Compare with Figure 26 (the other half of the same bird frozen at 0°F.).

Figure 24.

is difficult to say whether the ice formed in short columns or whether the ice column assumed the alternating bulging and constricted pattern remaining in the fiber, but they were probably lenticular in shape. The size or width of the vacuoles varied from very small openings to spaces one-third, one-half or three-fourths the width of the fiber. Sometimes there were several small vacuoles in one fiber (Figure 25). The length of the ice space also varied from short vacuoles to columns extending long distances in the fiber. Chambers and Hale (1932) suggested that the fiber is dehydrated as the water is evidently withdrawn from the fibers in advance of the forming ice column. This results in the ice columns which do not extend the full length of the fiber.

Attention should be called to the fact that the appearance of the size and shape of the vacuole would be partially determined by the cutting of the fiber, that is, whether the cut was oblique, across a wave or kink, on the edge or in the middle of a fiber.

It was often difficult under low magnification to determine whether a vacuole was within a fiber or was a space between two fibers. However, when the ends of the vacuole were found within a fiber (see lower part of vacuole in Figure 23) this was evidence of the formation of a vacuole by forcing the myofibrils apart.

Vacuoles and histological structure. In general, the

vacuoles were found in straight parts of fibers, especially in birds aged a short period of time. An occasional vacuole was found in a wavy fiber, but this was the exception instead of the rule. No vacuoles were found in fibers with turbulent striae or rigor nodes. These observations suggest, although further work would be necessary before definite conclusions can be drawn, that the histological condition or structure of the fiber may have some effect on the location of the ice crystals.

Vacuoles in cooked tissues. Vacuoles were found in the fibers of the cooked frozen tissues far more frequently than in those of the thawed, uncooked frozen tissues. Lowe (1947) suggests the following explanation:

> When ice crystals of the frozen uncooked tissues melt, the resulting water may be re-absorbed by the muscle tissues. Thus the cavity formed within the fiber from the ice may practically close when the tissues thaw. However, some vacuoles are observed in the thawed uncooked tissues. But when poultry is cooked from 20 to 40 per cent of the initial weight may be lost. The average for this study was about 28 per cent, a large proportion of which is water. As the chicken tissues are dehydrated during cooking some of this water is changed to vapor. If the sarcolemma of the fiber had not been broken during the freezing, the expansion of this vapor during heating could expand and fill the collapsed cavity formerly occupied by ice. Since water, under suitable conditions, in being transformed into steam may increase in volume approximately 1600 times, the initial size of the cavity formed by ice may even exceed its original size. The cooking coagulates and sets the fiber protoplasm, so that the vacuole remains in the cooked, cooled tissue.

If, in the expansion of the steam the initial size of the cavity is expanded and the sarcolemma breaks, an explanation is offered for the appearance of some tissues. In some fibers vacuoles are found within the cooked fiber, but one wall of the fiber has burst, leaving jagged edges.

Vacuoles and striations. Usually the cross striation around the vacuoles were very distinct (Figures 23 and 24). Sometimes both longitudinal and cross striae were evident as in Figures 21 and 25.

Inter-fibrillar freezing. The evidences of inter-fibrillar freezing were difficult to detect in the thawed uncooked fibers. Apparently the fibers which had been pushed aside by the ice crystals went back to their original position when the ice melted. However, indentations were found along the sides of fibers which had been frozen and cooked more often than in the unfrozen cooked fibers. The indentations along the sides of the fibers frozen at 0°F. and then thawed and cooked are shown in Figure 26. Note the granular material in the indentations. These granular-filled indentations varried in size and shape and occurred in the frozen tissues more frequently than in the unfrozen muscle. Occasionally evidences of intra-fibrillar freezing were found in birds frozen at 0°F., especially along the edges of the section where freezing would occur first and more rapidly.

The fibers from the frozen halves of chickens without keel bones, the cut side, had more vacuoles and injury to the fibers than those from the uncut side. The variation

Fig. 25. Cooked pectoralis major muscle.
Frozen at -30°F., 2-hour fowl.
(Magnification, 675x)

Showing several small vacuoles in one fiber.

Fig. 26. Cooked pectoralis major muscle. Frozen at 0°F., 30-minute roaster 0-8R. (Magnification, 675x)

Showing the indentations along the sides of fibers filled with granular material.

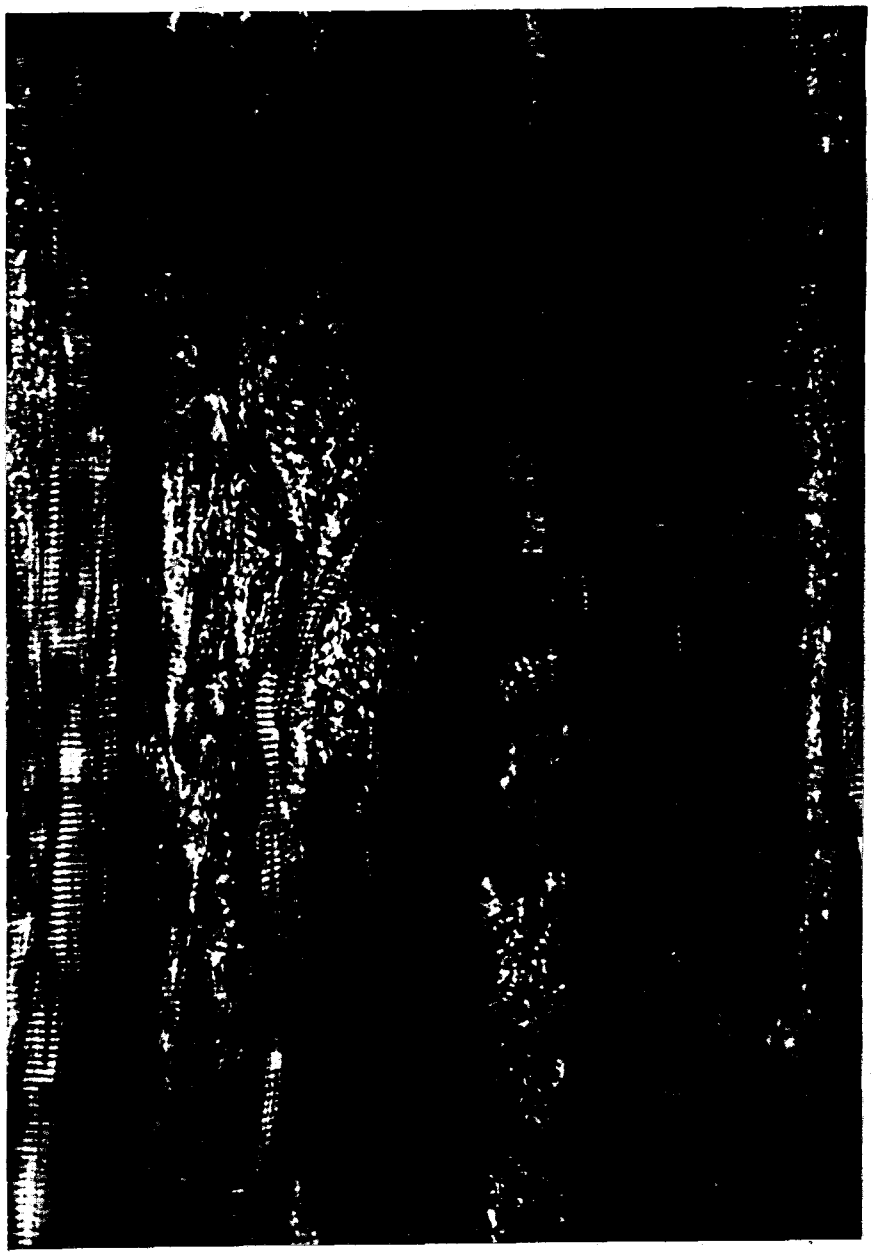


Figure 26.

between the amount of vacuoles occurring in roasters and fowl was no greater than that occurring between individual birds. However, fowl frozen at 0°F. appeared to have more fibers with indentations than the roasters frozen at 0°F.

Effect of aging before freezing on the characteristics of muscle tissue

Fibers. Waves, kinks and S twists were found throughout the sections of roasters and fowl in all the aging periods. However, there were more wavy fibers, kinks, twists and macro-waves in the tissues of birds aged one and two hours. As stated previously, waves were not so characteristic of the cooked muscle as they were of the uncooked muscle, but some waves and kinks were found. Zig-zags were observed only in the uncooked muscles of birds aged short periods of time. Waves in fibers of a fowl aged 30 minutes and a roaster aged one hour are shown in Figure 27. Note in the bird aged one hour the waves are deeper and all the fibers in the area are involved in the same pattern (Figure 27, lower picture). Kinks and twists can be seen at the bend of the waves. In Figure 27, upper picture, the waves are not so deep and not all the fibers are involved, as some of the fibers are straight. In general, as aging progressed beyond two hours, there was a tendency for the fibers to become straighter, with fewer twists, kinks, waves and zig-zag contractions.

Fig. 27, Upper picture. Uncooked pectoralis major muscle. Frozen at 0°F., 30-minute fowl 15L. (Magnification, 130x)

Showing rather shallow waves and straight fibers found in birds aged 30 minutes before freezing.

Fig. 27, Lower picture. Uncooked pectoralis major muscle. Frozen at -30°F., 1-hour roaster 23R. (Magnification, 90x)

Showing deep waves in which all the fibers of the area are involved, found in birds aged one or two hours before freezing.

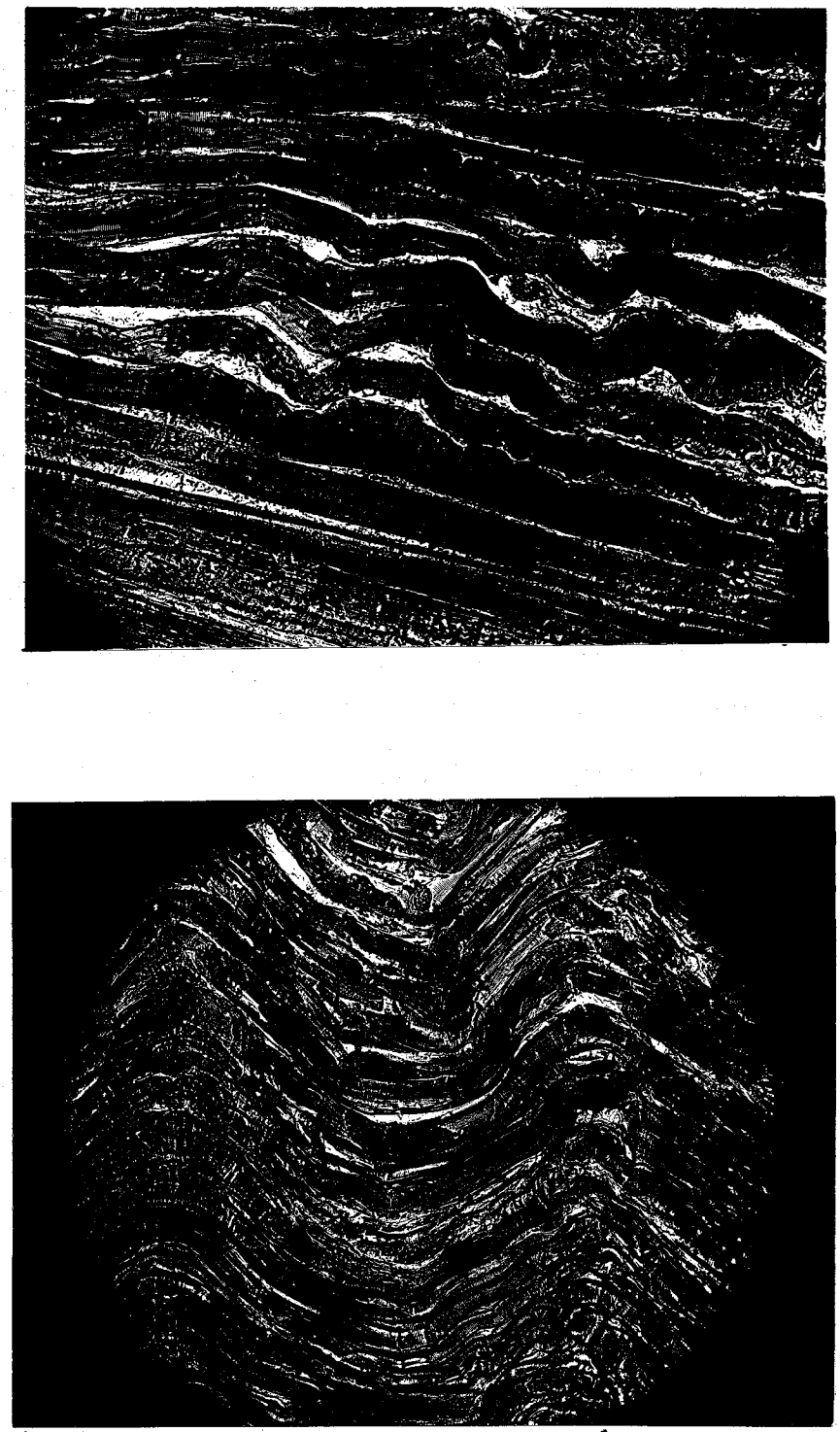


Figure 27.

Striae. In the fibers of birds aged 30 minutes or one hour there was a great deal of variation in the prominence of the striations. In some fibers the longitudinal striae were distinct, in others the cross striae were clear, and often both the cross and longitudinal striae were pronounced so the fibers looked like checked gingham. As aging progressed the cross striations became increasingly more prominent and in a greater proportion of the fibers.

Turbulent fibers were observed in some of the birds in all the aging periods. However, only one bird aged 24 hours showed this loss of alignment of cross striations. The cause of these turbulent fibers is not known. Turbulent fibers did not exhibit any disintegration or vacuoles. In some sections large numbers of fibers are turbulent.

Nodes. In general, the number of nodes found in the tissues increased as aging progressed. Usually the nodes in the birds aged short periods of time were not quite the same as the regular rigor nodes. Sometimes they were long or sometimes the nodes were short but the fiber did not bulge and very fine cross striae could be seen in the contracted area. The regular rigor nodes with bulging areas and constricted areas on either side became more numerous as aging progressed. Often these nodes were found along the edge of the sections of tissues, but sometimes they covered rather large areas. Regular rigor nodes are shown in Figure 28.

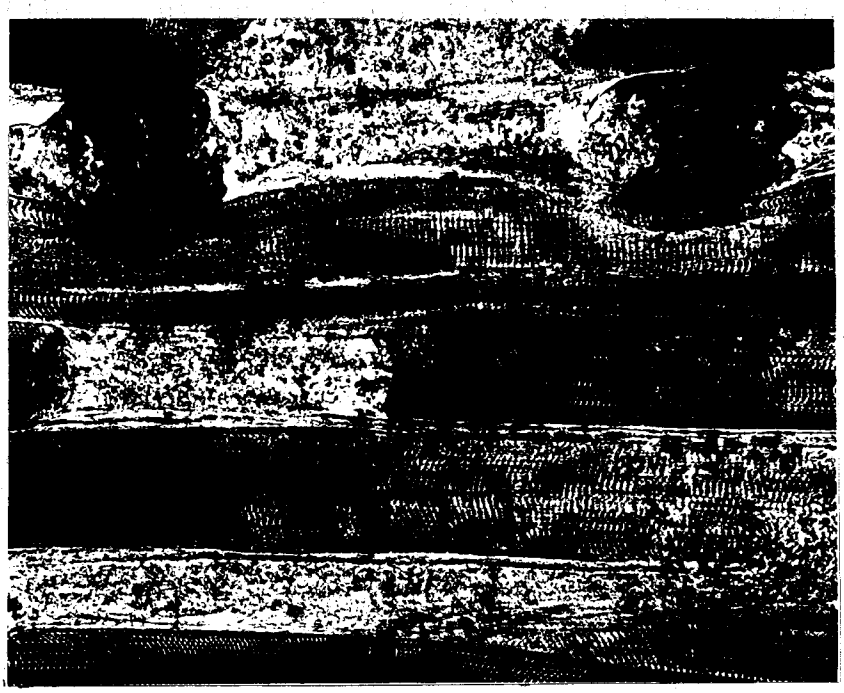


Fig. 28. Cooked pectoralis major muscle.
Fresh control, 24-hour roaster 91R.
(Magnification, 340x)

Showing rigor nodes in fiber at the top of the picture. Note disintegration between nodes and in the straight fibers.

A very interesting pattern of rigor ridges was found in the fibers of four birds aged 30 minutes, two birds aged one hour and one bird in the two-hour aging period. All the fibers in the sections made from four of the birds showed rigor ridges, and the other three showed just a few fibers involved in the rigor pattern. See Figure 29. The rigor ridges were not evident in the cooked muscle in this study.

Disintegration. Disintegration was evident in the rarefied areas of rigor nodes, in the disappearance of striations (which were replaced by granular material in cooked tissues) over an area of a fiber or in actual fissures in the fibers separating them into short segments. The amount of disintegration varied greatly from bird to bird, but was extensive in some birds of each aged group. This extensive disintegration was not found in the fibers of the pectoralis major (the muscle used in histological sections for microscopic observation in the present study) of the unfrozen halves of birds after aging 30 minutes and one and two hours before cooking. Neither was extensive disintegration found in the fibers of the pectoralis major of broilers aged less than three hours before cooking (Hanson et al, 1942) nor in fowl aged six hours or less (Stewart, Lowe, Harrison and McKeegan, 1945). Since disintegration of the muscle is believed to be caused by action of proteolytic enzymes, there must have been some period of time in which

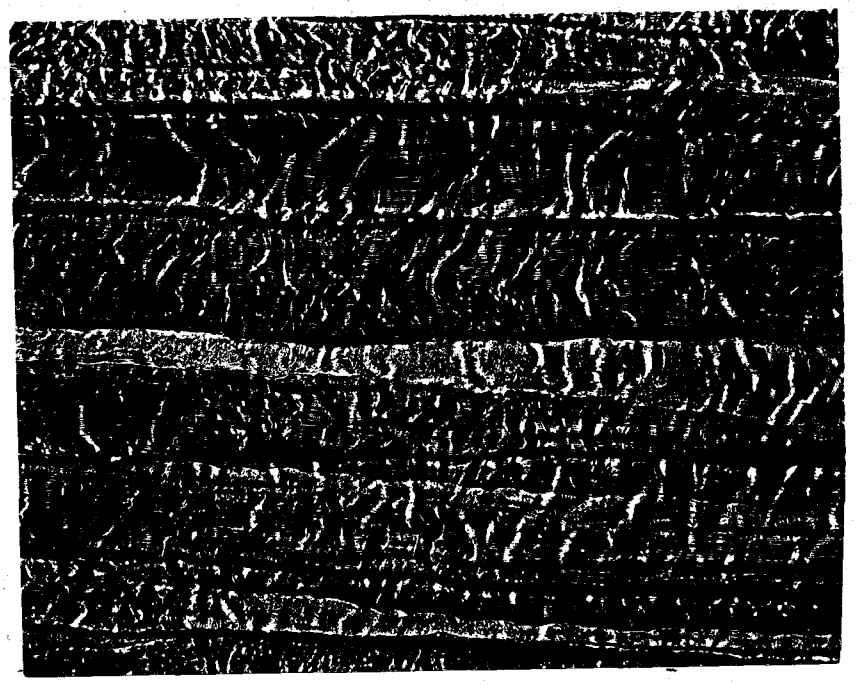


Fig. 29. Uncooked pectoralis major muscle. Frozen at -30°F., 2-hour fowl 45L. (Magnification, 150x)

Showing rigor ridge pattern with prominent longitudinal or turbulent striae between the ridges.

autolysis occurred before the samples for histological examination were removed and placed in the formalin solution for preservation. If this period of time for enzyme action occurred, was it long enough for the extensive disintegration to have been brought about?

Stewart, Hanson, Lowe and Austin (1945) showed that the pectoralis major muscle of broilers tenderized very rapidly with aging prior to cooking. The average tenderness score after three hours' aging was 8.0. Stewart, Lowe, Harrison and McKeegan (1945) also showed that tenderizing of the breast muscle occurred rapidly in fowl, but the rate was somewhat slower than in broilers.

The samples from the uncooked bird were sawed from the frozen carcass just before the half bird was placed in the refrigerator for thawing. Hence they were placed in the formalin solution while still frozen. Presumably enzyme action would stop soon after penetration of the formalin into the tissues. The samples for sectioning from the cooked bird were taken after cooking. During cooking enzyme action could continue at a variable rate until the enzyme was destroyed by heat. It is interesting that the ratings for extent of disintegration were, in general, from two to four times more extensive in the sections from the cooked than in the uncooked samples from the same half carcass.

Examination of the freezing curves (Figures 18 and 19)

shows that a longer interval elapsed between the time the half bird was placed in the freezer and the beginning of freezing for the carcasses aged the shorter periods of time than for those aged the longer periods. Thus for the halves frozen at 0°F. about two hours elapsed before the beginning of freezing of the muscles of the 30-minute aged group. The halves from the one- and two-hour aged groups began freezing in about 1.5 hours after being placed in the freezer. The longer time for autolysis to occur before freezing started, and the variation from bird to bird, could account for the extent of disintegration's being about the same in the 30-minute and in the one- and two-hour aged groups.

The more extensive disintegration in fibers of cooked halves of birds than in the uncooked fibers can be accounted for during the thawing period. The frozen halves were placed in a refrigerator (at approximately 4°C) for thawing before cooking. They were left in the refrigerator for 24 hours, but no record was kept of the time when defrosting was completed. All were thawed when removed from the refrigerator for preparation for the oven. Autolysis could occur after the tissues were thawed until stopped by the heat of cooking.

All the birds aged 24 hours had considerable protoplasmic disintegration and the fragility of the cross striae which gave the appearance of worn textile fibers. See Figure 30.

Fig. 30. Cooked pectoralis major muscle. Frozen at 0°F., 24-hour roaster 8-8R. (Magnification, 225x)

Showing disintegration of striations of the muscle fibers.

Vacuoles. In general, the number of vacuoles in fibers and the number of birds having vacuoles in the fibers decreased as aging progressed. The number of vacuoles found in the muscle fibers varied greatly from bird to bird and from area to area in the histological sections from the same bird. Hence, it is difficult to make any definite statement as to the exact number of vacuoles, but a decrease in approximate numbers of vacuoles was noticeable as aging progressed. Vacuoles were seen in all the cooked muscle fibers of birds aged 30 minutes before freezing at -30°F. The frequency of their occurrence varied from a vacuole in every fiber to one vacuole in 20 fibers, approximately. Certain areas of a section had many vacuoles; others had few. In the birds aged one hour and frozen at -30°F., some vacuoles were found in the muscle fibers of all but one bird. In some of the birds vacuoles were found in only one in approximately 50 or 100 fibers. Two birds in the two-hour aged group did not have vacuoles in the fibers frozen at -30°F., and the vacuoles were not as numerous as in the previous aging periods. More of the fibers in the two-hour aged group showed indentations, the injury to the side of muscle indicative of inter-fibrillar crystal damage. Only two birds aged six hours had many vacuoles in the fibers and two others had just a few vacuoles. After 24 hours of aging, it was difficult to find any vacuoles, although a few were found. Thus, the location of ice crystals is determined also by aging. Similar results were

obtained by Stewart, Hanson, Lowe and Austin (1945) who found that muscle fibers of broilers aged 18 hours before freezing contained no vacuoles, whereas fibers of broilers aged two hours and frozen at low temperatures contained many vacuoles.

As aging progresses there is less evidence of intra-fibrillar freezing and a tendency for inter-fibrillar freezing to increase. However, in birds aged 24 hours it is difficult to differentiate between disintegration and evidences of injury due to ice crystal injury.

Effect of freezing temperature upon characteristics of fiber

There appeared to be some differences in the uncooked fibers frozen at 0° and at -30°F., but the striae did not seem to be affected by the freezing temperatures used. Waves, kinks and rigor ridges seemed to be characteristic of the fibers frozen at 0°F., except those aged 24 hours, which seemed to have about the same distribution of wavy and straight fibers at both freezing temperatures. It might be difficult to prove that these differences were due to the freezing temperature as there is considerable variation in the characteristics of fibers in different areas of the same muscle and from bird to bird. Fibers found in birds frozen at -30°F. are shown in Figure 31.

Nodes. The variation observed in the occurrence of nodes in the fibers of birds frozen at 0° and -30°F. may or may not have been due to the difference in the freezing

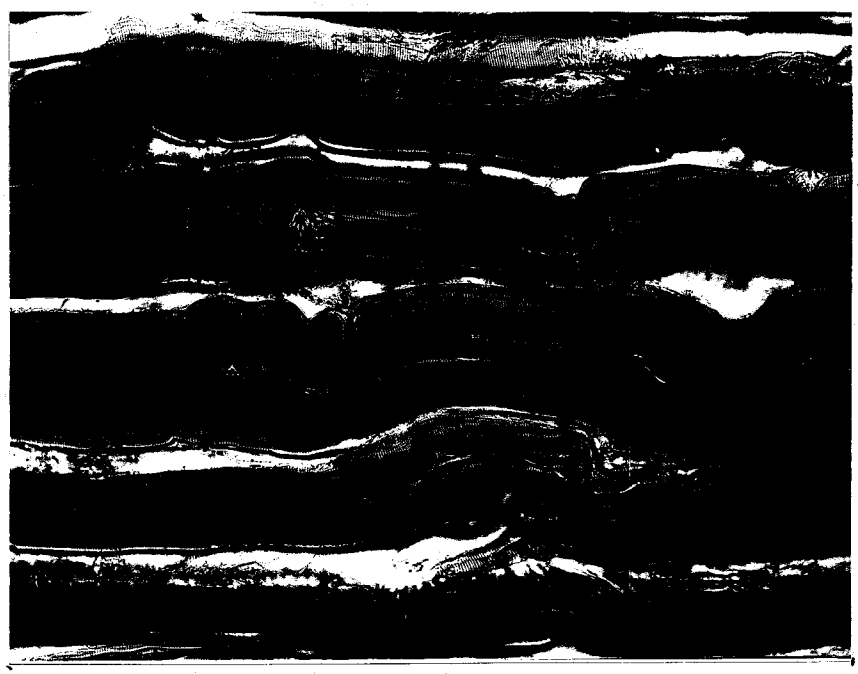


Fig. 31. Uncooked pectoralis major muscle. Frozen at -30°F., 30-minute fowl 5L. (Magnification, 150x)

Showing wavy, kinky fibers found in birds frozen at -30°F.

temperature. However, it is of interest to note that the number of nodes observed varied somewhat in the uncooked fibers of birds in the different age groups up to the six-hour aging period. Also there was a great variation in the number of nodes found in birds receiving the same treatment. Birds aged 24 hours had about the same number of rigor nodes regardless of the freezing temperature. After cooking, the halves frozen at -30°F. seemed to have more nodes in the fibers. This may have been circumstantial because when the roasters which had both sides frozen were compared, there was an approximately equal distribution of nodes for the two freezing temperatures.

Disintegration. There was an obvious difference in the amount of disintegration found in the fibers of birds aged 30 minutes and then frozen. The larger amount of disintegration found in the birds frozen at 0°F. might be accounted for by the fact that the enzymes had a longer time to act in the cooling period preceding freezing, and in the thawing period, because of the higher freezing temperature.

Vacuoles. Many more vacuoles were found in the fibers of birds frozen at -30°F. although occasional vacuoles were seen in the birds frozen at 0°F. It is possible that a fiber in which a longitudinal cut was made near the edge containing an indentation might resemble a fiber with a vacuole; however, the few cross sections that were made showed a very

few fibers frozen at 0°F. with vacuoles in the center of the fibers, which was evidence of intra-fibrillar freezing. The vacuoles found in fibers frozen at -30°F. are shown in Figure 32. This photomicrograph was taken at a lower magnification to give some idea of how frequently the vacuoles occurred in fibers. Only an occasional vacuole was found in a few of the sections of the birds aged 24 hours. After aging 24 hours and then freezing, the appearance of the fibers was similar in all the birds. The appearance of fibers frozen at 0°F. after aging for 24 hours is shown in Figure 33, and the fibers of the other half of the same bird frozen at -30°F. are shown in Figure 34. Thus the rate of freezing, aging before freezing and the histological structure are factors which may affect the size and location of ice crystals in frozen muscle fibers.

Indentations. Indentations were found more frequently in the fibers of the birds frozen at 0°F. However, some fibers with indentations were seen in the fibers of birds frozen at -30°F. The number of fibers showing this injury increased somewhat as aging progressed up to six hours of aging. As in the case of fibers frozen at -30°F., there was little evidence of ice crystal injury in the fibers of birds held 24 hours before freezing at 0°F.

An interesting series of photomicrographs of fibers taken from the same bird after various treatments are

Fig. 32. Cooked pectoralis major muscle. Frozen at -30°F., two-hour fowl 45L. (Magnification, 150x)

Showing vacuoles found in fibers frozen at -30°F.

Fig. 33. Cooked pectoralis major muscle. Frozen at 0°F., 24-hour roaster 8-8R. (Magnification, 675x)

Showing the disintegration of cross striations found in birds aged 24 hours.

Figure 33.

Fig. 34. Cooked pectoralis major muscle. Frozen at -30°F., 24-hour roaster 8-8L. (Magnification, 675x)

Showing disintegration of cross striae.

Note the ragged appearance of the cross striae similar to a worn fabric.

Figure 34.

presented in Figures 35, 36, 37 and 38. The histological appearance of fibers taken from the fresh half of bird before freezing is shown in Figure 35. The varied appearance of the striations is typical of fresh chicken muscle. The fibers shown in Figure 36 were obtained from the half of the bird frozen at -30°F. after aging for six hours. Note the vacuole in the top fiber which extends in from the left, then appears to stop at the constriction in the fiber and another vacuole seen in the right-hand side of the same fiber. There is an interesting vacuole in the fiber at the bottom of the picture. Apparently the sarcolemma was able to withstand the pressure exerted by the ice formation. In Figure 37 the cooked fibers of the same bird aged six hours and frozen at -30°F. are shown. The fiber containing a vacuole has fibers with disintegrated areas on either side. Notice the rough edges of the striations in which disintegration has occurred and the granular exudate which replaced the fiber striations. Fibers from the other half of the bird which had been frozen at 0°F. after aging six hours are shown in Figure 38. Indentations in the fibers filled with granular material (typical of the injury due to inter-fibrillar freezing) are evident.

From the evidence presented, it may be concluded that freezing poultry muscle at -30°F. produces some intra-fibrillar freezing and some inter-fibrillar freezing, whereas

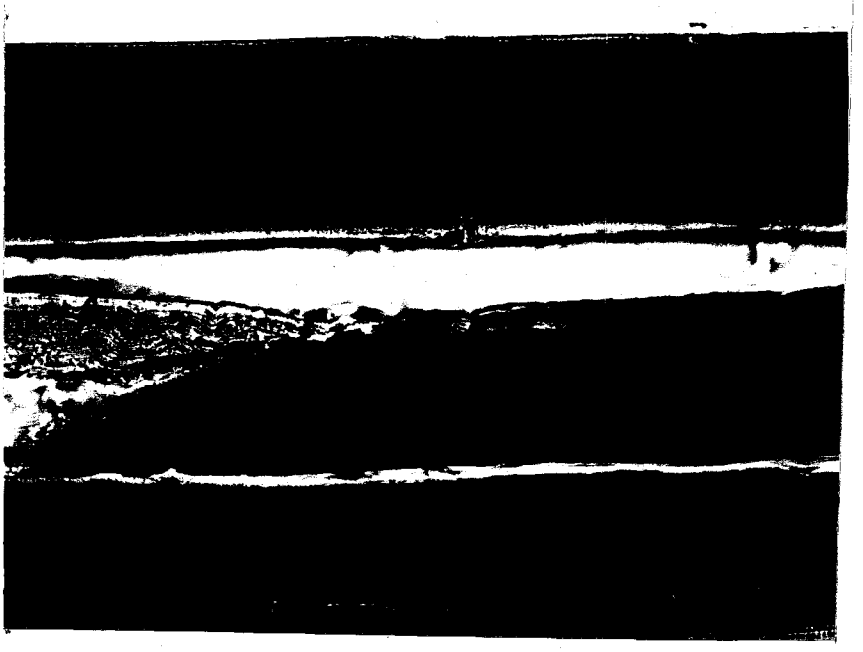


Fig. 35. Uncooked pectoralis major muscle. Fresh control, 6-hour roaster 7-8R. (Magnification, 340x)

Note that the striae, which are prominent, vary in the different fibers.

Fig. 36. Uncooked pectoralis major muscle. Frozen at -30°F., 6-hour roaster 7-8L. (Magnification, 340x)

Note the vacuole in the top fiber which extends in from the left and appears to stop at the constriction in the fiber; also vacuole in bottom fiber with sarcolemma apparently intact.

Fig. 37. Cooked pectoralis major muscle. Frozen at -30°F., 6-hour roaster 7-8L. (Magnification, 675x)

Showing fiber containing a vacuole and two fibers with disintegrated areas on either side.

Figure 37.

Fig. 38. Cooked pectoralis major muscle. Frozen at 0°F., 6-hour roaster 7-8R. (Magnification, 675x)

Showing indentations in the fibers filled with granular material (typical of the injury due to inter-fibrillar freezing).

Figure 38.

freezing at 0°F. results in inter-fibrillar freezing. The size and location of the ice crystals is determined also by the extent of aging and the histological structure of the muscle tissue at the time of freezing.

These results are in agreement with the findings of Ramsbottom and Koonz (1939). They reported that in poultry muscle frozen at -15°F. (-26.1°C.) "extra-fiber" freezing occurred exclusively. When similar muscles were frozen at -32°F. (-35.6°C.), "intra-fiber" freezing occurred in some of the fibers, whereas others lost water which froze external to the fiber. Shrewsbury et al. (1942) reported that freezing pork muscle at a temperature of -26°F. (-32.2°C.) produced both "extra-fiber" and "intra-fiber" freezing.

SUMMARY

A study was made of the histological and palatability changes in roasters and fowl which occurred during freezing at 0°F. (-17.8°C.) and -30°F. (-34.4°C.). The birds were aged 30 minutes, one, two, six, or 24 hours prior to freezing. The 50 chickens used in this study were 20 White Leghorn fowl, 24 Rhode Island Red roasters and six Barred Rock roasters. The chickens were killed and eviscerated warm. After aging, the birds were cut in half. In one part of the experiment one half of the carcass was used as a fresh control and the other half was frozen. In this part of the study two roasters and two fowl were cut in half and one side was frozen at 0° or -30°F. in still air for each of the five aging periods, making a total of four replications for each treatment. In the other part of the experiment both sides of the roaster were frozen, one at 0°F. and the other half at -30°F. Two replications were made at each aging period.

A constantan-copper thermocouple to be used in recording the rate of freezing was placed in the thigh of each half of bird. The halves of chickens were wrapped in pliofilm bags and placed, cavity side down, on a metal shelf in the freezing room, where they froze in still air at 0° and -30°F. They were left in the freezing compartments 24 hours. The rate of freezing was recorded automatically every six minutes by a

Leeds and Northrup temperature-recording Micromax. The frozen half of bird was thawed in the refrigerator at approximately 39.2°F. (4.0°C.); each half bird remained 24 hours in the refrigerator.

All the chickens were roasted in uncovered pans at an oven temperature of 302°F. (150°C.) until the thermometer in the thigh of the bird registered 195°F. (90.5°C.).

The results were determined by both objective and subjective tests. Palatability scores of the judges gave an indication of the desirability of the aroma, flavor, juiciness and tenderness of the birds. The shearing apparatus was used to measure the tenderness of the pectoralis major muscle of the breast of the chicken. Curves indicating the rate of freezing of the chickens under the various conditions were obtained from the data recorded by the Micromax. Samples of the raw fresh halves, the cooked fresh control halves, the raw frozen and the cooked frozen halves of birds were prepared for microscopic examination.

An average of approximately three hours, 24 minutes was required for all halves of chickens frozen at -30°F. to cool from 28° to 0°F. This was a freezing rate of approximately 5.5°F. per hour, where as the halves frozen at 0°F. required eight hours, 40 minutes for the temperature to drop from 28° to 0°F. This was a freezing rate of approximately 2.1°F. per hour, or less than one half the rate at -30°F. The fowl frozen at 0° and -30°F. usually took less time to

freeze than the roasters. This might be explained partly by the fact that the fowl weighed less than the roasters. There was an interesting difference in the thermal arrest in the freezing curves of birds frozen at the same temperature but aged different lengths of time. Chickens aged six or 24 hours required less time to freeze than those aged 30 minutes, one or two hours.

The total cooking losses at each aging period varied as much for the frozen halves of birds as for the fresh control halves. A slightly greater total cooking loss was found in birds frozen at 0°F. after aging six and 24 hours prior to freezing. Losses in weight during cooking showed a linear relationship with the total cooking time, except for the halves of birds frozen at 0°F.

In general the flavor and aroma scores showed little variation between treatments. The flavor scores for the pectoralis major ranged from 8.2 to 8.8, the aroma scores from 8.7 to 9.0.

The juiciness scores of the fresh control halves of birds aged 24 hours were rated two points lower than the halves aged 30 minutes. However, the decrease was not linear with aging; between the one- and six-hour aging periods the juiciness scores increased somewhat and then decreased again at 24 hours. The halves of birds frozen at 0°F. and then thawed showed a very definite linear decrease in juiciness with aging. The juiciness scores for the halves frozen at 0°F.

were lower than the fresh controls except in the one-hour aging period. Freezing the halves of chickens at -30°F. and thawing had little effect on the juiciness scores at any of the aging periods. After 24 hours aging, the juiciness scores of the fresh control halves and those frozen at -30°F. were practically the same. The pectoral secundus was rated less juicy than the pectoralis major; however, the variation with aging was surprisingly similar. In general, freezing at -30°F. and thawing had the least effect on the juiciness scores of both muscles. There is a trend for the higher freezing temperature to increase the dryness of both the pectoralis major and the pectoralis secundus muscles.

After the 30-minute aging period there was a noticeable decrease in tenderness of the birds aged one or two hours; then the tenderness increased rapidly up to 24 hours of aging. Except for an increase in tenderness between the 30-minute and one-hour aging periods, the tenderness scores of the fresh control halves of fowl followed essentially the same pattern as for the roasters, the difference being merely one of degree. Since the fowl aged 30 minutes were rated -2.3 in tenderness, the increase to a score of 8.1 in the halves of fowl aged 24 hours was most striking. An average tenderness score of 9.3 was reached for the pectoralis major muscle of fresh control halves of roasters in 24 hours and a score of 8.1 for the fresh control halves of fowl in 24 hours of aging.

The pectoralis secundus muscle of the fresh control halves was rated more tender than the pectoralis major. The effect of aging on the tenderness of the pectoralis secundus muscle was similar to that found for the pectoralis major muscle of the fresh control halves of both roasters and fowl. An average tenderness score of 9.0 was reached for the pectoralis secundus muscle of the roasters in six hours and of 8.1 for the fowl in 24 hours of aging. Aging of the fresh control halves of chicken produced variations in tenderness which were highly significant.

The tenderness curves for the halves of birds frozen at 0° and -30°F. showed an entirely different picture from that of the fresh controls. There was little variation in the tenderness with increase in aging time. The differences in tenderness scores between the fresh control halves and those receiving the freezing-thawing treatment were highly significant. Freezing at 0°F. and -30°F. followed by thawing at 39.2°F. (24 hours) definitely increased the tenderness of all the frozen halves of birds except those aged 24 hours. Apparently in birds that have been ripened 24 hours prior to freezing the effect of aging on tenderness is as great as, if not greater than the effect of the freezing-thawing treatment. Thus, tenderness was increased by freezing and thawing but to a decreasing degree with increase in aging time. The differences in the tenderness scores for the halves frozen at 0°F. and -30°F. were not significant.

Histological studies of the fresh control muscle fibers showed that in general as aging progressed there was a tendency for the fibers to become straighter with fewer waves, kinks and twists. The cross striations became more distinct with aging, but disintegration of the cross striae increased as aging progressed. These microscopic changes in the fibers were accompanied by an increase in the tenderness of the muscle.

The frozen muscle fibers were usually better differentiated and the cross striae more evident than in the unfrozen muscle. The amount of disintegration varied greatly from bird to bird, but was obviously more extensive in the fibers of birds frozen after short periods of aging than in the fibers of the fresh control paired halves. Here, again, the changes in histological structure were accompanied by increase in tenderness. That is, in general, birds in which the muscle fibers have rather prominent cross striations, fewer waves and kinks, and considerable disintegration are rated higher in tenderness.

Vacuoles, the small cavities or spaces assumed to indicate the space formerly occupied by the ice crystal, were found most frequently in the cooked muscle fibers of birds aged 30 minutes, one or two hours before freezing. This evidence of intra-fibrillar freezing varied from bird to bird, but was usually found in the straight part of the fiber. The width of the vacuoles varied from a very small opening to

spaces three-fourths the width of the fiber. The length varied and also the shape of the opening. In the cooked fibers the vacuoles were filled with a granular substance.

From the evidence obtained in this study, it appears that freezing poultry muscle at -30°F. results in some intra-fibrillar and some inter-fibrillar freezing. The extent of the intra-fibrillar freezing also varies with the length of the aging period and the histological condition of the muscle fibers. Indentations, the small notches or depressions in the sides of the muscle fibers presumed to result from the pressure of ice crystals between the fibers, were found more frequently in the fibers of birds frozen at 0°F.

The size and location of ice crystals are determined by the rate of freezing, the extent of aging and the histological structure of the muscle tissue at the time of freezing.

CONCLUSIONS

The conclusions from this study were drawn on the basis of halves of roasters and fowl aged 30 minutes, one, two, six or 24 hours prior to cooking or to freezing at 0° or -30°F., then thawing and cooking. Biological variation must always be kept in mind in evaluating the results of this investigation. Differences in palatability and histological changes between the fresh control and the frozen halves of chicken are the result of the freezing-thawing treatment.

Under the conditions of this study the following conclusions can be drawn:

1. The freezing rate of birds frozen at 0°F. was approximately one-half of the freezing rate at -30°F.

2. The length of aging the bird before freezing affected the freezing rate; those aged shorter periods of time required longer to freeze.

3. No differences in tenderness of poultry owing to the freezing temperature were noted.

4. Freezing at the higher temperature tended to produce less juicy breast muscle than freezing at the lower temperature.

5. The tenderness of poultry aged six hours or less is definitely increased by freezing and thawing.

SELECTED REFERENCES

Astbury, W. T. 1934 X-ray studies of protein structure. Cold Spring Harbor Sym. on Quant. Biol. 2:15-24.

--------- and Dickinson, S. 1940 X-ray studies of the molecular structure of myosin. Proc. Roy. Soc. (London) 129(B):307-332.

Balls, A. K., and Kies, M. W. 1946 In Anderson, J. A. Enzymes and their role in wheat technology. p.233. New York, Interscience Publishers, Inc.

Brady, D. E. 1937 A study of the factors influencing tenderness and texture of beef. Proc. Am. Soc. Animal Production 30:246-249.

Bremer, J. L. 1944 A textbook of histology. 6th ed. p.131. Philadelphia, P. Blakiston's Son and Co., Inc.

Callow, E. H. 1938 The electrical resistance and micro-structure of muscular tissue. Gt. Brit. Dept. Sci. and Ind. Res. Food Invest. Board Rept. 1937:46-49.

Carey, E. J. 1940 Wave mechanics of striated muscle. XVI. Effects of experimental variations in temperature and of microcapillarity on the cross striations in muscle. Arch. of Path. 30:1041-1072.

---------, Zeit, W, and Massopust, L. 1942 Wave mechanics in striated muscle. XIX. Experimental variations in number and pattern of living muscle striae produced by heat. Am. J. Anat. 70:119-133.

Chambers, R., and Hale, H. P. 1932 The formation of ice in protoplasm. Proc. Roy. Soc. (London) 110(B):336-352.

DuBois, C. W., Tressler, D. K., and Fenton, F. 1942 The effect of the rate of freezing and temperature of storage on the quality of frozen poultry. Refrig. Eng. 44:93-99.

Emmett, A. D., and Grindley, H. S. 1909 A preliminary study of the effect of cold storage on beef and poultry. J. Ind. Eng. Chem. 1:413-436, 580-597.

Fitzgerald, G. A., and Nickerson, J. T. R. Effect of time
1939 and temperature of holding undrawn poultry upon its quality. Seventh World's Poultry Congress, Proc. 7:509-519.

Hammond, John Some factors affecting the quality and
1940 composition of meat. Chem. and Ind. 18:521-525.

Hankins, O. C., and Hiner, R. L. Tenderness of beef as
1940 affected by different freezing temperatures. Abstract in Proc. Am. Soc. Animal Production 33: 260-261. Published in full under title "Freezing makes beef tenderer." Food Ind. (1940) 12:49-51.

Hanson, H. L. Palatability studies on poultry. III. Changes
1941 occurring in New York dressed broilers held at 35°F. Unpublished M. S. Thesis. Ames, Iowa. Iowa State College Library.

----------, Stewart, G. F., and Lowe, B. Palatability and
1942 histological changes occurring in New York dressed broilers held at 1.7°C. (35°F.). Food Research 7:148-160.

Harrison, D. Histological, physical and organoleptic
1947 changes in two grades of beef during aging. Unpublished Ph. D. Thesis. Ames, Iowa. Iowa State College Library.

Helser, M. D., Nelson, P. M., and Lowe, B. Influence of the
1930 animal's age upon the quality and palatability of beef. Iowa Agr. Expt. Sta. Bul. 272.

Hepburn, J. S. The behavior of enzymes at low temperatures.
1915 J. Franklin Institute 179:581-585.

Hiner, R. L., and Hankins, O. G. Tenderness of beef as
1941 affected by aging with and without subsequent freezing. Refrig. Eng. 42:172-174, 198.

Hoagland, R., McBryde, C. N., and Powick, C. W. Changes in
1917 fresh beef during cold storage above freezing. U. S. Dept. Agr. Bul. 433.

Hoffert, E. Palatability studies on poultry. V. Influence
1947 of defrosting methods. Unpublished M. S. Thesis. Ames, Iowa. Iowa State College Library.

Hoffman, K. L. 1939 Palatability studies on Poultry. I. Chilling prior to freezing, plus variation of the length of storage after freezing before drawing. II. Washing versus wiping the body cavity after drawing. Unpublished M. S. Thesis. Ames, Iowa. Iowa State College Library.

Johnson, H. V. 1946 Water content changes of poultry held in frozen storage as related to palatability. Unpublished Ph. D. Thesis. Ames, Iowa Iowa State College Library.

Koonz, C. H., and Ramsbottom, J. M. 1939 A method for studying the histological structure of frozen products. I. Poultry. Food Research 4:117-128.

--------- and --------- 1939 Susceptibility of frozen-defrosted poultry meat to drip. Food Research 4:485-492.

Lampitt, L. H., and Moran, T. 1933 The palatability of rapidly frozen meat. J. Soc. Chem. Ind. 52:143-146T.

Lehman, K. B. 1907 Studien über die Zähigkeit des Fleisches und ihre Urashen. Arch. Hyg. 63:134-179.

Lineweaver, H. 1939 Energy of activation of enzyme reactions and their velocity below 0°. J. Am. Chem. Soc. 61:403-408.

Lowe, B. 1939 Effect of drawing before freezing on the palatability of poultry. Seventh World's Poultry Congress, Proc. 7:500-505.

--------- 1943 Experimental cookery. 3rd ed. p.205-235. New York, John Wiley and Sons, Inc.

--------- 1947 Information on frozen chicken. Private communication.

--------- and Stewart, G. F. 1946 The cutting of the breast muscles of poultry soon after killing and its effect on tenderness after subsequent storage and cooking. Unpublished.

---------, ---------, Harrison, D. L., and McKeegan, M. 1946 Palatability studies on poultry. The organoleptic, rigor, and histologic changes in roasters after slaughter. Spec. Rept. (Unpublished.)

Mackintosh, D. L., Hall, J. L., and Vail, G. E. Some observations pertaining to the tenderness of meat. Proc. Am. Soc. Animal Production 29:285-289.
1936

Maximow, A. A., and Bloom, W. A textbook of histology. 5th ed. p.156. Philadelphia, W. B. Saunders and Co.
1944

Mirsky, A. E. The change in state of the proteins of muscle. J. Gen. Physiol. 19:571-575.
1935

Mitchell, H. H., Zimmerman, R. L., and Hamilton, T. S. The determination of the amount of connective tissue in meat. J. Biol. Chem. 71:379-387.
1927

Moran, T. Recent advances in the low-temperature preservation of food-stuffs. J. Soc. Chem. Ind. 48:245T-251T.
1929

--------- The frozen state in mammalian muscle. Proc. Roy. Soc. (London) 107(B):182-187.
1931

--------- Rapid freezing. Critical rate of cooling. J. Soc. Chem. Ind. 51:16-20T.
1932

--------- and Smith, E. C. B. Post-mortem changes in animal tissues--the conditioning or ripening of beef. Gt. Brit. Dept. Sci. and Ind. Res. Food Invest. Board Spec. Rept. 36.
1929

Nuttall, G. H. F., and Gardiner, J. S. The histological changes in frozen fish and the alterations in the taste and physiological properties of their flesh. J. Hygiene 17:56-62.
1918

Parnas, J. K. The chemistry of muscle. Ann. Rev. Biochem. 2:321.
1933

Paul, P. C. Changes in palatability, microscopic appearance and electrical resistance in beef during the onset and passing of rigor and during subsequent storage. Unpublished Ph. D. Thesis. Ames, Iowa. Iowa State College Library.
1943

--------- and Child, A. M. Effect of freezing and thawing beef muscle upon press fluid, losses, and tenderness. Food Research 2:339-347.
1937

Pennington, M. E. A chemical, bacteriological and histological study of cold-stored poultry. Rapports I-III. Intern. Congress of Refrig. 2:216-260.
1908

---------, Hepburn, J. S., St. John, E. Q., and Witmer, E. The influence of temperatures below freezing on the changes in chemical composition, bacterial content, and histological structure of common fowl. Proc. Am. Soc. Biol. Chem., 11th Ann. Meeting, J. Biol. Chem. 29:33-34.
1917

Plank, R. Neue Untersuchungen über die Konservierung von Fleisch und Fischen durch das Gefrierverfahrn. 13. Kalorimetrische Untersuchungen an Gefrierfleisch. Zeitschrift f. die Gesamte Kälte-Industrie 32:141-147.
1925

Poole, G. Recent progress in quick freezing. Refrig. Eng. 29:69-73, 102.
1935

Ramsbottom, J. M., and Koonz, C. H. Relationship between time of freezing beef after slaughter and amount of drip. Food Research 5:423-429.
1940

---------, Strandine, E. J., and Koonz, C. H. Comparative tenderness of representative beef muscles Food Research 10:497-509.
1945

Sair, L., and Cook, W. H. Effect of precooling and rate of freezing on the quality of dressed poultry. Canadian J. of Res. 16(Sec. D):139-152.
1938

Sherrill, L. G. Quick freezing of filleted fish. Food Ind. 1:33-35.
1928

Short, B. Specific heat of foodstuffs. I. An experimental determination. Univ. Texas Pub. 4432, Bur. Eng. Res. Eng. Res. Series 40. p.7-26.
1944

Shrewsbury, C., Horne, L, Braun, W., Jordan, R., Milligan, O., Vestal, C., and Weitkamp, N. Chemical, histological and palatability changes in pork during freezing and storage in the frozen state. Purdue Univ. Agr. Expt. Sta. Bul. 472:1-35.
1942

Sizer, I. W. Effects of temperature on enzyme kinetics. In Advances in Enzymology 3:35-62.
1943

--------- and Josephson, E. S. Kinetics as a function of temperature of lipase, trypsin and invertase activity from -70 to 50°C. (-94 to 122°F.). Food Research 7:201-209.
1942

Smith, E. C. B. 1937 Native and denatured muscle proteins. Proc. Roy. Soc. (London) 124(B):136-150.

--------- 1939 Changes in elasticity of mammalian muscle undergoing rigor mortis. J. Physiol. 96: 176-193.

Smorodintsev, I. A. 1943 Theory of the freezing process of meat. J. Applied Chem. (U.S.S.R.) 16:368-374. (Original not seen; abstracted in Chem Abstr. 38:6410.)

--------- 1943 Chemical changes in the preservation and defrosting of frozen meat. J. Applied Chem. (U.S.S.R.) (Original not seen; abstracted in Chem. Abstr. 38:6410.)

--------- and Nikolaeva, N. V. 1936 Modification of cathepsin during the autolysis of muscular tissue. Compt. rend. acad. sci. (U.R.S.S.) (N.S.) 3: 375-377. (Original not seen; abstracted in Chem. Abstr. 31:720.)

--------- and --------- 1942 Changes in the activity of peptidase on autolysis of muscular tissue. Compt. rend. acad. sci. U.R.S.S. 34:233-234. (In English) (Original not seen; abstracted in Chem Abstr. 37:2833.)

Speidel, C. C., and Jordan, H. E. 1942 On the constancy of the number of sarcomeres within individual muscle fibers. Anat. Rec. 82:470.

Stewart, G. F., Hanson, H. L., Lowe, B., and Austin, J. J. 1945 Effects of aging, freezing rate, and storage period on palatability of broilers. Food Research 10:16-27.

---------, Lowe, B., Harrison, D., and McKeegan, M. 1945 Palatability studies on fowl. I. The organoleptic, rigor, and histologic changes in fowl after slaughter. Spec. Rept. (Unpublished.) Iowa State College Library.

---------, Lowe, B., and Morr, M. 1941 Post-mortem changes in New York dressed poultry at 35°F. U. S. Egg and Poultry Mag. 47:542-544, 571-572.

Stiles, W. 1922 The preservation of food by freezing with special reference to fish and meat: A study in general physiology. Gt. Brit. Dept. Sci. Ind. Res. Food Invest. Board Spec. Rept. 7.

Szent-Gyorgyi, A. 1945 Studies on muscle. Acta Physiol. Scand., Supplement 25. 9:1-115.

--------- 1946 Contraction and chemical structure of the muscle fiber. J. Colloid Sci. 1:1-19.

Tressler, D. K., Birdseye, C., and Murray, W. T. 1932 Tenderness of meat. I. Determination of relative tenderness of chilled and quick-frozen beef. Ind. Eng. Chem. 24:242-245.

--------- and Murray, W. T. 1932 Tenderness of meat. II. Determination of a period of aging "grade A" beef required to produce a tender quick-frozen product. Ind. Eng. Chem. 24:890-892.

Vickery, J. R. 1926 Studies on the refrigeration of meat. II. The freezing of beef and mutton press juices. Aust. J. Exp. Biol. and Med. Sci. 3:81-88.

Wills, R. R. 1946 Organoleptic and histological changes in eviscerated frozen poultry stored under varying conditions of temperature and time. Unpublished M. S. Thesis. Ames, Iowa. Iowa State College Library.

ACKNOWLEDGMENTS

The author wishes to express her sincere appreciation to Miss Belle Lowe for her guidance, interest and generous help in this research. The author also wishes to acknowledge the interest and cooperation of Dr. George F. Stewart. She extends her thanks to the Misses Anna Dale and Dorothy Harrison for scoring and to Mrs. Betty Stepp for her cooperation. Appreciation for help in making the statistical analysis is extended to Mr. Paul Homeyer, and for making the photomicrographs to Mr. John Staby.

APPENDIX

POULTRY COOKING RECORD
GRADING CHART FOR COOKED POULTRY

Sample No. _____ Kind of Meat _____(Thigh or Breast) Date _____

Factor		10	9	8	7	6	5	4	3	2	1	Remarks
		Extremely good	Very good	Good	plus	Medium	minus	Fair	Poor	Very poor	Extremely poor	
Aroma												
Flavor	Fat											
	Lean											
Tenderness		Extremely tender	Very tender	Tender	plus	Medium	minus	Fair	Tough	Very tough	Extremely tough	
Juiciness		Extremely juicy	Very juicy	Juicy	plus	Medium	minus	Fair	Dry	Very dry	Extremely dry	

DESCRIPTIVE TERMS

Flavor

1. Flat _____
2. Mild _____
3. Mellowed _____
4. High, gamey _____
5. Rich _____
6. Raw _____
7. Strong _____
8. Old _____
9. Bitter _____
10. Foreign _____
11. Acid _____
12. Sweet _____

Normal or abnormal?

Aroma

1. Mild _____
2. Sharp _____
3. Strong _____
4. Faint _____
5. Foreign _____
6. Sour _____

Normal or abnormal?

	Light	Medium	Dark
Breast			
1. White	_____	_____	_____
2. Pinkish white	_____	_____	_____
3. Grayish white	_____	_____	_____
4. Yellowish white	_____	_____	_____
5. Grayish yellow	_____	_____	_____
Thigh			
1. Yellowish white	_____	_____	_____
2. Red brown	_____	_____	_____
3. Pinkish white	_____	_____	_____

F-28

Preference _____
(among samples judged at one time

Scorer _____

170

Table A. Flavor and aroma scores for the breast of halves of chicken aged varying periods of time before cooking or freezing and cooking.

Time of aging	No. of bird	Freezing temperature	Pectoralis Major		Pectoralis Secundus	
			Aroma	Flavor	Aroma	Flavor
30 min.	Roasters					
	1L	-30	9.0	8.8	9.0	8.5
	1R		9.0	9.0	9.0	9.0
	3L		9.0	8.3	9.0	8.0
	3R	-30	9.0	8.5	9.0	8.3
	11L	0	9.0	8.8	8.8	8.5
	11R		8.8	9.0	8.8	8.8
	13L		8.8	8.8	9.0	8.8
	13R	0	9.0	8.8	9.0	9.0
	0-8L	-30	9.0	8.5	9.0	8.5
	0-8R	0	9.0	8.8	8.8	8.0
	1-8L	0	9.0	8.5	9.0	8.3
	1-8R	-30	9.0	8.8	9.0	8.5
	Fowl					
	5L	-30	9.0	8.5	9.0	8.3
	5R		9.0	8.3	9.0	8.5
	6L	-30	9.0	8.5	9.0	8.5
	6R		8.8	8.8	8.5	8.3
	15L	0	9.0	8.8	9.0	8.8
	15R		9.0	8.8	9.0	8.8
	16L	0	9.0	8.5	9.0	8.8
	16R		8.8	8.5	8.8	8.5
1 hour	Roasters					
	21L	-30	9.0	8.5	8.5	7.8
	21R		8.3	7.3	8.5	7.0
	23L		8.5	8.5	8.5	8.3
	23R	-30	9.0	8.8	9.0	8.3
	31L	0	9.0	9.0	9.0	9.0
	31R		9.0	8.8	8.5	7.8
	33L		9.0	9.0	9.0	8.3
	33R	0	9.0	8.5	9.0	7.8
	2-8L	0	8.8	8.3	8.8	8.3
	2-8R	-30	8.5	8.5	8.5	8.3
	3-8L	-30	9.0	8.7	9.0	8.0
	3-8R	0	9.0	9.0	9.0	8.3

(continued)

Table A (continued)

Time of aging	No. of bird	Freezing temperature	Pectoralis Major		Pectoralis Secundus	
			Aroma	Flavor	Aroma	Flavor
1 hour	Fowl					
	25L	-30	8.8	7.3	9.0	6.0
	25R		9.0	8.5	9.0	8.3
	26L	-30	9.0	8.5	9.0	8.5
	26R		8.8	8.5	8.5	8.3
	35L	0	8.8	8.8	8.8	7.5
	35R		8.8	7.5	8.8	6.5
	36L	0	8.8	9.0	8.8	8.5
	36R		8.8	7.5	9.0	7.3
2 hours	Roasters					
	42L		8.8	8.3	8.8	8.0
	42R	-30	9.0	8.5	9.0	8.3
	44L	-30	9.0	8.8	8.8	8.8
	44R		8.3	8.0	8.3	8.3
	52L		8.8	8.8	9.0	8.8
	52R	0	9.0	8.8	9.0	7.8
	53L		8.8	8.5	8.5	8.3
	53R	0	8.8	8.3	8.8	8.0
	4-8L	-30	9.0	9.0	9.0	8.3
	4-8R	0	9.0	8.5	8.8	8.0
	5-8L	0	9.0	8.8	8.8	8.5
	5-8R	-30	8.8	8.5	8.8	6.5
	Fowl					
	45L	-30	9.0	8.8	9.0	7.3
	45R		8.8	8.3	8.8	8.3
	46L	-30	8.8	8.8	8.8	8.3
	46R		8.5	7.8	8.5	8.3
	55L	0	8.8	8.0	8.8	7.8
	55R		8.8	8.5	8.5	8.3
	56L	0	8.8	8.8	8.8	8.5
	56R		9.0	8.5	9.0	8.3
6 hours	Roasters					
	62L		9.0	9.3	9.0	8.5
	62R	-30	9.0	9.3	9.0	8.8
	63L		8.5	7.8	8.5	7.8
	63R	-30	9.0	8.7	9.0	8.0
	71L	0	9.0	8.7	9.0	8.0

(continued)

Table A (continued)

Time of aging	No. of bird	Freezing temperature	Pectoralis Major		Pectoralis Secundus	
			Aroma	Flavor	Aroma	Flavor
6 hours	Roasters (cont.)					
	71R		8.8	8.8	8.5	8.5
	72L		8.5	8.8	8.5	8.5
	72R	0	8.8	8.5	8.8	8.0
	6-8L	0	8.8	8.5	8.8	8.0
	6-8R	-30	9.0	8.5	8.8	8.3
	7-8L	0	9.0	8.5	9.0	8.8
	7-8R	-30	9.0	8.8	9.0	8.0
	Fowl					
	65L	-30	8.8	8.3	8.8	8.3
	65R		7.8	8.3	8.5	8.8
	66L	-30	9.0	8.5	9.0	8.5
	66R		8.8	8.3	8.8	7.0
	75L	0	9.0	8.5	9.0	8.5
	75R		9.0	8.8	9.0	8.5
	76L	0	9.0	8.8	9.0	8.5
	76R		9.0	8.5	9.0	8.3
24 hrs.	Roasters					
	81L	-30	8.8	9.0	8.8	8.5
	81R		9.0	8.7	9.0	7.7
	82L		8.7	8.0	8.7	8.0
	82R	-30	8.8	8.5	8.8	8.3
	91L	0	9.0	8.8	9.0	8.8
	91R		8.8	8.3	9.0	7.8
	92L		8.7	8.7	8.3	8.0
	92R	0	8.8	8.5	8.3	8.0
	8-8L	-30	8.8	9.0	8.5	7.5
	8-8R	0	8.8	8.5	8.5	7.3
	9-8L	0	8.8	7.8	8.8	8.3
	9-8R	-30	8.5	8.3	8.5	7.0
	Fowl					
	85L	-30	8.8	8.5	8.8	7.3
	85R		8.8	8.5	9.0	8.3
	86L	-30	8.8	8.3	8.8	8.0
	86R		8.0	8.3	8.5	8.0
	95L	0	9.0	8.5	8.8	8.0
	95R		9.0	8.0	9.0	8.5
	96L	0	8.8	8.3	8.8	8.3
	96R		9.0	8.3	8.8	8.3

Table B. Tenderness and juiciness scores for the breast of halves of chicken and shear force in pounds for the pectoralis major muscle of the breast of halves of chicken. Grouped according to time of aging, i.e., time between killing and cooking or freezing.

No. of bird	Freezing temperature	Shear force (lbs.)	Pectoralis Major		Pectoralis Sec.	
			Tenderness	Juiciness	Tenderness	Juiciness
30 min. Roasters						
1L*	-30	7.3	7.8	6.3	9.5	4.0
1R		12.4	5.8	7.3	7.8	4.8
3L*		23.3	1.5	5.8	2.5	4.5
3R	-30	3.5	9.3	6.3	8.8	4.3
11L*	0	7.5	8.0	6.0	8.5	3.8
11R		16.5	6.8	7.5	8.3	5.3
13L*		16.0	4.3	7.5	7.5	7.8
13R	0	4.0	9.0	6.8	9.3	5.0
0-8L*	-30	4.4	8.3	5.8	9.3	4.5
0-8R	0	2.8	9.8	6.0	9.3	4.5
1-8L	0	3.0	9.5	5.5	9.5	4.0
1-8R*	-30	4.9	7.8	5.3	8.0	5.0
Fowl						
5L*	-30	7.5	6.3	5.5	4.8	4.3
5R		26.6	4.5	6.8	7.3	4.0
6L	-30	7.4	8.3	3.5	8.3	3.5
6R*		29.0	-0.5	7.8	1.8	4.8
15L*	0	7.2	7.3	6.8	8.0	4.3
15R		25.0	-7.3	7.8	0.8	6.3
16L	0	7.6	8.0	6.3	7.3	4.8
16R*		36.7	-5.8	7.8	-5.5	6.5
1 hour Roasters						
21L*	-30	5.4	8.3	6.5	8.8	4.8
21R		27.0	2.8	5.3	6.8	3.8
23L*		18.6	2.3	7.3	2.5	5.3
23R	-30	2.8	9.3	6.8	9.5	5.0
31L*	0	6.9	4.3	6.8	8.3	5.3
31R		15.3	4.0	6.3	8.0	3.5
33L		16.6	1.7	5.8	7.0	4.3
33R*	0	6.7	8.3	4.3	9.5	2.5
2-8L	0	4.9	9.0	2.8	9.8	2.5
2-8R*	-30	5.1	8.8	5.0	9.5	2.8

(continued)

*Cut side.

Table B (continued)

No. of bird	Freezing temperature	Shear force (lbs.)	Pectoralis Major		Pectoralis Sec.	
			Tenderness	Juiciness	Tenderness	Juiciness
3-8L*	-30	5.9	8.7	7.3	6.0	5.7
3-8R	0	4.7	9.3	8.0	6.3	7.0
Fowl						
25L*	-30	14.3	6.8	2.8	7.0	3.0
25R		11.3	1.8	4.8	4.5	4.0
26L	-30	7.5	7.3	7.5	4.8	6.0
26R*		26.5	2.3	4.0	5.0	3.0
35L*	0	10.3	5.0	6.3	5.8	4.3
35R		35.0	0.3	6.3	2.0	5.3
36L	0	6.2	7.0	7.0	5.8	4.5
36R*		22.7	-2.5	4.8	3.0	4.0
2 hours Roasters						
42L		23.3	2.0	5.8	6.5	4.0
42R*	-30	5.9	7.5	5.5	9.5	4.0
44L	-30	5.3	8.8	5.8	8.0	4.5
44R*		16.9	2.0	5.8	1.8	5.8
52L		19.3	5.0	7.3	8.3	5.3
52R*	0	6.7	7.8	6.3	7.0	4.0
53L*		22.3	2.0	5.8	6.5	3.5
53R	0	5.4	8.8	4.8	7.5	3.8
4-8L*	-30	6.5	8.0	7.0	9.3	3.8
4-8R	0	3.7	9.8	4.5	9.5	3.3
5-8L	0	5.5	8.3	5.8	7.8	3.8
5-8R*	-30	7.0	6.3	4.3	8.0	3.3
Fowl						
45L*	-30	9.7	8.0	5.5	3.5	5.0
45R		28.2	2.0	6.5	4.3	5.0
46L	-30	10.5	8.0	7.3	7.3	5.0
46R*		25.9	-3.8	6.5	6.0	3.3
55L*	0	7.8	6.0	5.0	5.5	2.8
55R		23.6	2.3	4.8	4.0	5.3
56L	0	9.9	7.5	5.5	5.8	5.5
56R*		26.3	1.0	6.8	3.5	4.8
6 hours Roasters						
62L		7.0	9.3	6.8	8.8	4.8
62R*	-30	6.5	7.8	7.8	8.8	5.3
63L*		8.2	9.0	4.8	8.8	3.5
63R	-30	7.4	8.0	4.7	8.7	3.7
71L*	0	7.6	7.0	5.3	9.3	2.7

(continued)

Table B (continued)

No. of bird	Freezing temperature	Shear force (lbs.)	Pectoralis Major		Pectoralis Sec.	
			Tenderness	Juiciness	Tenderness	Juiciness
6 hours Roasters (cont.)						
71R		8.0	7.0	7.5	8.8	5.8
72L		6.3	9.0	5.5	9.5	4.0
72R*	0	2.6	9.3	5.0	9.3	3.8
6-8L	0	3.9	9.8	4.3	8.3	4.3
6-8R*	-30	5.9	6.3	5.3	8.5	4.3
7-8R	0	4.4	9.0	5.5	9.5	4.0
7-8L*	-30	6.2	6.3	7.3	8.5	3.5
Fowl						
65L*	-30	10.6	5.8	5.8	7.0	4.3
65R		26.0	-1.3	8.3	5.0	7.5
66L	-30	5.7	7.3	5.8	8.8	5.0
66R*		10.6	6.5	4.3	8.0	2.8
75L*	0	9.4	5.5	6.3	4.0	4.0
75R		12.8	5.0	7.5	4.5	7.0
76L	0	7.1	8.5	3.3	8.8	2.0
76R*		8.1	8.5	5.5	8.8	4.8
24 hrs. Roasters						
81L*	-30	3.7	9.8	7.0	9.8	4.8
81R		4.1	9.3	5.7	9.0	2.3
82L		6.7	9.3	4.3	8.0	2.7
82R*	-30	6.8	9.0	4.3	4.8	4.5
91L*	0	4.2	9.3	4.5	9.5	3.8
91R		3.9	9.5	4.5	9.8	5.0
92L		7.6	9.0	6.3	8.7	5.3
92R*	0	3.5	9.0	4.0	8.0	3.3
8-8L*	-30	6.4	8.5	6.3	6.5	3.3
8-8R	0	6.5	8.5	5.5	8.3	3.5
9-8L	0	4.7	9.0	5.0	9.0	4.5
9-8R*	-30	4.9	8.8	4.0	9.3	2.8
Fowl						
85L*	-30	6.4	6.5	5.8	7.3	3.5
85R		4.7	8.3	7.3	8.8	5.5
86L	-30	7.0	6.3	5.0	8.0	4.0
86R*		6.3	8.3	5.8	8.8	3.8
95L*	0	11.2	5.5	3.5	7.8	2.3
95R		7.3	7.5	4.8	5.8	3.3
96L	0	6.8	8.5	3.5	8.8	4.0
96R*		10.1	8.3	3.0	9.0	2.0

*Cut side.

Table C. The losses in weight (volatile, drippings and total) during cooking of halves of roasters aged various periods of time between killing and freezing or cooking

Bird		Breed	Weight before cooking	Cooking losses			Total cooking time
				Volatile	Dripping	Total	
No.	°F.		gms.	%	%	%	min.
		30-minute aging					
1L	-30	RIR[1]	825	22.8	3.9	26.7	140
1R			892	27.1	2.6	29.7	138
3L		RIR	1032	27.4	4.0	31.4	175
3R	-30		1025	23.9	4.0	27.9	178
11L	0	RIR	817	21.4	5.1	26.6	135
11R			853	24.6	6.1	30.7	130
13L		RIR	710	18.6	3.4	28.0	90
13R			770	21.8	5.1	26.9	120
0-8L	-30	RIR	1012	25.2	6.8	32.0	171
0-8R	0		1046	20.6	6.7	27.2	168
1-8L	0	RIR	983	25.1	7.4	32.6	180
1-8R	-30		954	25.2	5.3	30.5	172
		1-hour aging					
21L	-30	RIR	748	26.2	4.8	31.0	110
21R			800	25.9	5.3	31.1	140
23L		RIR	681	23.3	2.9	26.3	108
23R	-30		733	24.6	3.4	28.0	148
31L	0	BR[2]	920	25.1	3.5	28.6	170
31R			807	27.3	3.5	30.8	167
33L		RIR	1222	--	--	26.8	140
33R	0		1065	20.3	5.3	25.6	210
2-8L	0	RIR	1215	19.4	7.4	26.8	155
2-8R	-30		1152	22.0	7.3	29.3	160
3-8L	-30	RIR	638	5.6	5.5	11.1	106
3-8R	0		674	5.6	5.9	11.6	95
		2-hour aging					
42L		RIR	737	26.7	5.0	31.8	137
42R	-30		712	26.4	4.4	30.8	127
44L	-30	RIR	752	23.4	6.9	30.3	120
44R			730	22.9	4.5	27.4	110

(continued)

[1]RIR = Rhode Island Red [2]BR = Barred Rock

Table C (continued)

Bird No.	Bird °F.	Breed	Weight before cooking	Cooking losses: Volatile	Cooking losses: Dripping	Cooking losses: Total	Total cooking time
			gms.	%	%	%	min.
		2-hour aging (cont.)					
52L		BR	1043	25.1	3.9	29.1	140
52R	0		942	23.6	3.7	27.3	140
53L		RIR	1121	18.8	6.4	25.2	100
53R	0		1067	19.9	7.5	27.4	140
4-8L	-30	RIR	931	19.2	6.1	25.3	139
4-8R	0		942	25.4	5.0	30.4	170
5-8L	0	RIR	982	23.1	4.1	27.2	155
5-8R	-30		894	26.2	5.6	31.8	177
		6-hour aging					
62L		RIR	806	25.2	3.0	28.2	137
62R	-30		757	--	--	23.0	110
63L		RIR	923	18.9	5.9	24.7	130
63R	-30		797	13.0	3.8	16.8	145
71L	0	BR	685	15.2	2.5	17.7	127
71R			820	13.8	3.0	16.8	90
72L		RIR	909	23.0	7.2	30.1	140
72R	0		840	24.2	6.3	30.5	143
6-8L	0	RIR	1156	23.6	8.4	32.0	167
6-8R	-30		1112	19.9	7.6	27.5	130
7-8L	-30	RIR	985	17.4	10.2	27.5	128
7-8R	0		1008	23.9	8.4	32.3	160
		24-hour aging					
81L	-30	BR	935	20.9	3.4	24.3	135
81R			940	22.4	4.0	26.5	130
82L		BR	866	23.0	6.4	29.3	135
82R	-30		798	26.4	5.6	32.1	160
91L	0	RIR	1120	25.4	7.9	33.3	140
91R			1086	26.3	5.7	32.0	167
92L		RIR	917	24.3	6.3	30.6	138
92R	0		780	24.8	5.7	30.5	150
8-8L	-30	BR	862	21.2	5.5	26.7	120
8-8R	0		835	23.9	3.0	26.9	135
9-8L	0	RIR	1070	16.9	10.9	27.9	120
9-8R	-30		955	22.4	10.6	33.0	120

Table D. The losses in weight (volatile, drippings and total) during cooking of halves of fowl aged various periods of time between killing and freezing or cooking

Bird		Weight before cooking	Cooking losses			Total cooking time
			Volatile	Dripping	Total	
No.	°F.	gms.	%	%	%	min.
		30-minute aging				
5L	-30	605	19.3	8.6	27.8	123
5R		685	19.1	8.4	27.7	108
6L	-30	581	23.1	9.0	32.0	117
6R		611	19.3	9.0	28.3	95
15L	0	640	18.0	10.5	28.4	100
15R		700	13.3	13.3	26.7	98
16L	0	678	15.9	8.7	24.6	93
16R		651	20.0	7.2	27.2	95
		1-hour aging				
25L	-30	704	16.1	13.8	29.8	103
25R		755	19.7	13.4	33.1	102
26L	-30	786	9.1	17.2	26.2	100
26R		708	16.4	17.9	34.3	106
35L	0	765	14.9	14.6	29.5	100
35R		874	16.8	11.8	28.6	85
36L	0	475	18.5	6.7	25.3	107
36R		470	18.1	8.5	26.6	92
		2-hour aging				
45L	-30	1012	16.6	13.5	30.1	150
45R		1048	14.6	12.1	26.7	115
46L	-30	575	13.7	8.9	22.6	80
46R		628	14.2	11.8	26.0	73
55L	0	619	16.6	11.0	27.6	100
55R		650	13.2	10.3	23.5	80
56L	0	633	15.5	11.1	26.5	90
56R		613	11.6	13.9	25.4	80

(continued)

Table D (continued)

Bird No.	°F.	Weight before cooking gms.	Cooking losses: Volatile %	Cooking losses: Dripping %	Cooking losses: Total %	Total cooking time min.
		6-hour aging				
65L	-30	412	17.0	7.8	24.8	77
65R		423	12.1	8.0	20.1	60
66L	-30	674	19.9	10.4	30.3	113
66R		660	25.2	8.9	34.1	104
75L	0	461	18.9	7.2	26.0	80
75R		450	15.1	10.0	25.1	83
76L	0	692	25.5	11.6	37.1	160
76R		684	20.8	11.3	32.0	125
		24-hour aging				
85L	-30	565	16.3	11.7	28.0	87
85R		570	20.2	10.7	30.9	117
86L	-30	666	17.4	10.1	27.5	115
86R		604	13.2	9.8	23.0	67
95L	0	565	25.3	10.6	35.9	140
95R		605	19.2	10.7	29.9	93
96L	0	838	21.2	14.7	35.9	140
96R		775	25.8	12.3	38.1	145

Table E. The weight, initial temperature, and total rise in temperature of roasters aged various periods of time before cooking or freezing

Bird no.	Freezing temp.	Weight	Initial temp.	Total temp. rise	Temp. rise per min.
	°F.	gms.	°F.	°F.	°F.
	30-minute aging				
1L	-30	825	35.6	159.4	1.099
1R	-30	892	93.2	101.8	0.738
3L		1032	84.2	110.8	0.629
3R	-30	1025	30.2	164.8	0.926
11L	0	817	33.8	161.2	1.194
11R		853	91.4	103.6	0.797
13L		710	93.2	101.8	1.131
13R	0	770	30.2	164.8	1.373
0-8L	-30	1012	30.2	164.8	0.964
0-8R	0	1046	30.2	164.8	0.981
1-8L	0	983	39.2	155.8	0.866
1-8R	-30	954	30.2	164.8	0.958
	1-hour aging				
21L	-30	748	33.8	161.2	1.465
21R		800	63.0	132.0	0.943
23L		681	82.4	112.6	1.043
23R	-30	733	35.6	159.4	1.077
31L	0	920	33.8	161.2	0.948
31R		807	58.0	137.0	0.820
33L		1222	63.0	132.0	0.943
33R	0	1065	30.2	164.8	0.785
2-8L	0	1215	30.2	164.8	1.063
2-8R	-30	1152	30.2	164.8	1.030
3-8L	-30	638	39.2	155.8	1.470
3-8R	0	674	39.2	155.8	1.640
	2-hour aging				
42L		737	73.4	121.6	0.888
42R	-30	712	33.8	161.2	1.269
44L	-30	752	46.4	148.6	1.238
44R		730	82.4	112.6	1.024

(continued)

Table E (continued)

Bird no.	Freezing temp.	Weight	Initial temp.	Total temp. rise	Temp. rise per min.
	°F.	gms.	°F.	°F.	°F.
	2-hour aging (cont.)				
52L		1043	82.4	112.6	0.804
52R	0	942	30.2	164.8	1.177
53L		1121	50.0	145.0	1.450
53R	0	1067	32.0	163.0	1.164
4-8L	-30	931	35.6	159.4	1.147
4-8R	0	942	35.6	159.4	0.938
5-8L	0	982	30.8	164.2	1.059
5-8R	-30	894	33.8	161.2	0.911
	6-hour aging				
62L		806	57.2	137.8	1.006
62R	-30	757	33.8	161.2	1.465
63L		923	60.8	134.2	1.032
63R	-30	797	35.6	159.4	1.099
71L	0	685	37.4	157.6	1.241
71R		820	59.0	136.0	1.511
72L		909	53.6	141.4	1.010
72R		840	39.2	155.8	1.090
6-8L	0	1156	35.6	159.4	0.954
6-8R	-30	1112	37.4	157.6	1.212
7-8L	-30	985	30.2	164.8	1.288
7-8R	0	1008	32.0	163.0	1.019
	24-hour aging				
81L	-30	935	35.6	159.4	1.181
81R		940	44.6	150.4	1.157
82L		866	42.8	152.2	1.127
82R	-30	798	37.4	157.6	0.985
91L	0	1120	35.6	159.4	1.139
91R		1086	42.8	152.2	0.911
92L		917	44.6	150.4	1.090
92R	0	780	41.0	154.0	1.027
8-8L	-30	862	37.4	157.6	1.313
8-8R	0	835	41.0	154.0	1.141
9-8L	0	1070	53.6	141.4	1.178
9-8R	-30	955	57.2	137.8	1.148

Table F. The weight, initial temperature, and total rise in temperature of fowl aged various periods of time before cooking or freezing.

Bird no.	Freezing temp.	Weight	Initial temp.	Total temp. rise	Temp. rise per min.
	°F.	gms.	°F.	°F.	°F.
	30-minute aging				
5L	-30	605	30.2	164.8	1.340
5R		685	89.6	105.4	0.976
6L	-30	581	39.2	155.8	1.332
6R		611	86.0	109.0	1.147
15L	0	640	39.2	155.8	1.558
15R		700	86.0	109.0	1.112
16L	0	678	42.8	152.2	1.637
16R		651	86.0	109.0	1.147
	1-hour aging				
25L	-30	704	42.8	152.2	1.478
25R		755	86.0	109.0	1.069
26L	-30	786	30.2	164.8	1.648
26R		708	84.2	110.8	1.045
35L	0	765	33.8	161.2	1.612
35R		874	86.0	109.0	1.282
36L	0	475	42.8	152.2	1.422
36R		470	82.4	112.6	1.224
	2-hour aging				
45L	-30	1012	32.0	163.0	1.087
45R		1048	86.0	109.0	0.948
46L	-30	575	44.6	150.4	1.880
46R		628	78.8	116.2	1.592
55L	0	619	33.8	161.2	1.612
55R		650	86.0	109.0	1.373
56L	0	633	42.8	152.2	1.691
56R		613	84.2	110.8	1.385

(continued)

Table F (continued)

Bird no.	Freezing temp.	Weight	Initial temp.	Total temp. rise	Temp. rise per min.
	°F.	gms.	°F.	°F.	°F.
	6-hour aging				
65L	-30	412	41.0	154.0	2.000
65R		423	64.4	130.6	2.177
66L	-30	674	37.4	157.6	1.395
66R		660	59.0	136.0	1.308
75L	0	461	46.4	148.6	1.858
75R		450	62.6	132.4	1.595
76L	0	692	42.8	152.2	0.951
76R		684	64.4	130.6	1.045
	24-hour aging				
85L	-30	565	42.8	152.2	1.749
85R		570	44.6	150.4	1.285
86L	-30	666	42.8	152.2	1.324
86R		604	57.2	137.8	2.057
95L	0	565	41.0	154.0	1.100
95R		605	59.0	136.0	1.462
96L	0	838	35.6	159.4	1.139
96R		775	57.2	137.8	0.950

Table G. Tenderness of the halves of roasters frozen at 0°F. and -30°F. after aging various periods of time as determined by tenderness scores of the pectoralis major and pectoralis secundus muscles of the breast and shear force of the pectoralis major muscle.

Aging period	Shear force		Tenderness scores			
	Pectoralis major		Pectoralis major		Pectoralis secundus	
	0°F.	-30°F.	0°F.	-30°F.	0°F.	-30°F.
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
30 minutes	2.9	4.7	9.7	8.7	9.4	8.7
1 hour	4.8	5.2	9.2	8.8	8.1	8.0
2 hours	4.7	6.8	9.1	7.7	8.7	8.7
6 hours	4.2	6.1	9.4	6.3	8.9	8.5
24 hours	5.6	5.7	8.8	8.7	8.7	7.9

Table H. Analysis of variance of tenderness scores of paired halves of roasters frozen at 0° and -30°F. after various periods of aging.

Source of variation	Degrees of freedom	Sum of squares	Mean square
Aging	4	14.80	3.70
Chickens (error a)	5	12.25	2.45
Freezing temperature	1	42.05	42.05**
Freezing temperature x aging	4	22.70	5.68**
Freezing temperature x chickens treated alike (error b)	5	1.00	0.20

** = highly significant