1946

Water content changes of poultry held in frozen storage as related to palatibility

Helen Virginia Johnson
Iowa State College

WATER CONTENT CHANGES OF POULTRY
HELD IN FROZEN STORAGE
AS RELATED TO PALATABILITY

by

Helen Virginia Johnson

A Thesis Submitted to the Graduate Faculty
for the Degree of

DOCTOR OF PHILOSOPHY

Major Subjects: Foods
Household Equipment

Approved:

Signature was redacted for privacy.

In Charge of Major Work

Signature was redacted for privacy.

Heads of Major Departments

Signature was redacted for privacy.

Dean of Graduate College

Iowa State College
1946

TABLE OF CONTENTS

INTRODUCTION

Poultry that is kept for a period of time in frozen storage may develop a characteristic dry powder-like texture. This texture, as indicated by palatability scores, is associated with a lack of juiciness. The role of water in changing from the free to the bound state or vice versa was believed to offer investigative possibilities in relation to palatability changes.

The methods for determining bound water are numerous, but the nature of poultry muscle placed a limitation on the methods that could be used. It seemed necessary to choose one least likely to effect changes in the protein itself. A method which would merely indicate a trend was considered satisfactory in this study since at best the work could only be of an exploratory nature.

There has been some argument on the subject of bound water. Some workers have denied its existence, whereas others have spent years working on the theory that it does exist. Bull (11,p.239) in a summary note states that bound water may or may not contribute greatly to the understanding of physiology and pathology, but it is extremely important for the understanding of protein reactions.

The measurement of bound water and free water in poultry muscle might prove to be an objective means of determining the factor of juiciness. However, the correlation of subjective measurements of water content with objective measurements of water content poses a problem.

In this study roasters were used as a medium for the investigation of the problem of waterbinding in frozen storage. The frozen storage of the birds was planned with respect to time and temperature variations. Although the same experimental treatment, breed, general size, and age of birds were used, the variation was expected to be high because of the biological nature of the working medium.

REVIEW OF LITERATURE

Protein Structure and Waterbinding

It is known that proteins are made up of amino acids joined together by the carboxyl group of one acid to the amino group on the alpha carbon of a second acid. This produces a long peptide chain containing several hundred amino acid residues.

It is also known that the amino acid side chains (the R groups) differ in their affinity for water. The water-loving groups are called hydrophilic, and the water-hating groups are called hydrophobic.

One of the important characteristics of proteins is their dependence upon the presence of water. In most cases they take up large quantities. Jordan Lloyd (29) suggests that water may either cling to the polar groups and be called "loosely bound" or it may be linked by hydrogen bonds with the oxygen and nitrogen atoms of the carbonyl, hydroxyl, imino, and amino groups of the structure.

Wherever hydrogen bonding can occur in the protein molecule, water can be added. Astbury (1) has summarized the possibilities of waterbinding by the hydrogen bond in the protein molecule as follows:

1. The bound water of constitution, which would include the linkage of water to such groups as: the hydroxyl, the carbonyl, the carboxyl, the imino, the amino, the amide, the ionized carboxyl, and the ionized amino groups.

2. The water taken up by salt-like linkages between the end groups of acidic and basic side chains. This theory is reenforced by the fact that the distance between the main chains in the direction of the side chains increases with water content. This distance reaches a maximum of 10A°.

Lloyd and Phillips (32) state that oxygen and nitrogen atoms in the polar groups unite more readily with water than does hydrogen. Both oxygen and nitrogen have more electrons to donate to an acceptor atom than do the other atoms present.

3. In backbone linkages one backbone chain may be joined to another by means of hydrogen bonds between the NH and CO groups. These joinings are responsible for the aggregation of polypeptide grids sometimes called crystallites. These linkages are direct and do not allow the entrance of the water molecule. As Astbury states it (11,p.875), "The spacing is remarkably constant (about 4½A°) from one protein to another and is uninfluenced by water content." Therefore the formation of polypeptide aggregates could not be expected to add water to the protein substance.

4. The intra-molecular transformation of keratin that takes place on stretching (α to β keratin) may involve the

rupture of hydrogen bonds. However, no statement is made regarding the association of water with these bonds.

The Relation of Hydrogen-ion Concentration to Waterbinding

Water may be bound to the protein molecule by means of charged groups (amino and carboxyl) which occur on the side chains and which have been ionized. Lloyd and Phillips (32) state that the power of the amino and carboxyl groups to hold water molecules is different when charged than in the uncharged state. As has been mentioned (1), the binding of water to these charged groups is by hydrogen bonding. This waterbinding power consequently changes with any shift in pH. Lloyd and Phillips (32) found three maxima of hydration for gelatin. They were in the acid and alkali range of pH and also at absolute neutral. These workers attributed some of the acid and alkali swelling to the formation of charged centers. At absolute neutral the swelling was caused by water coordinating with uncharged polar groups.

Bull (11, p.333) explains that when the pH of a gelatin gel is shifted from the isoelectric point, a Donnan equilibrium is established between the interior of the gel and the acid or base on the outside of the gel. This leads to electrolyte accumulation by the gel, with an increase in osmotic pressure inside, and water flows into the gel. This continues until the total swelling pressure is equal to the elastic strength of the gel.

Effect of Temperature on Waterbinding

Temperature affects the swelling of gelatin. Jordan Lloyd and Pleass (33) found that at pH 5.0 in the absence of salts, swelling increases slowly with rising temperature from 0° to 15° or 18°, after which, with further rise there was a decrease of swelling. They also noted that the swelling of gelatin in the presence of acid or alkali increases as an exponential function of the temperature.

The Effect of Salts on Waterbinding

Salts are an important influence in protein hydration. Lloyd and Pleass (33) have shown that 0.1 M NaCl decreases the swelling of gelatin over the entire pH range in the presence of .01 M HCl and .01 M NaOH. They also observed that at greater concentration salt induces a swelling which is in logarithmic ratio to its concentration. When gelatin is in solution as electrically charged particles, the effect of adding sodium chloride is mainly electrostatic. At the isoelectric point gelatin gels swell more in the presence of salts than in water because with adsorption of the salt ions there is a resulting greater hydration of the gelatin.

The Hydration of Muscle Proteins

Lloyd and Phillips (32) give a partial analysis of muscle proteins, as:

glutamic acid	16.48%
aspartic acid	3.21%
lysine	8.0 %
arginine	6.5 %

They classify glutamic acid and aspartic acid in the group of amino acid side chains showing some affinity for water, whereas lysine and arginine show pronounced affinity for water. Lloyd and Phillips (32) also state that muscle proteins may be expected to show maxima of hydration because of charged centers in both alkaline and acid ranges and should show a minimum at the isoelectric point.

The hydration of protein, according to Lloyd and Phillips (32), depends on the length of the side chains and the groups in the side chains. The classification of the side chains according to their affinity for water is given. Also, the length in A° is given.

Nil group		Slightly increasing	
Glycine	1.2A°	Tyrosine	7.5A°
Alanine	2.5A°	Tryptophane	12.5A°
Valine	3.7A°	Histidine	6.5A°
Iso leucine	5.0A°	Aspargine	
Nor leucine	5.0A°	Glutamic acid	5.1A°
Phenyl-alanine	6.3A°	B-hydroxy glutamic acid	3.8A°
Cystine	2.5A°	Proline	4A° (about)

Pronounced

Hydroxy proline	4A°
Serine	3.5A°
Lysine	8.8A°
B-hydroxy lysine	
B-hydroxy valine	

The Amino Acid Composition of Animal Tissue Proteins

There are relatively few comprehensive studies of the amino acid composition of tissue proteins. Beach, Munks and Robinson (4) found that the amino acid composition of the ten muscle meats (beef, veal, lamb, pork, chicken, turtle, codfish, salmon, frog legs, and shrimp) did not differ widely. The amino acids present in muscle in descending order of proportionality were lysine, serine, arginine, threonine, phenylalanine, tyrosine, methionine, histidine, and cystine.

The Proteins of Muscle

The proteins of muscle are of two types: the structural proteins and the intracellular or protoplasmic proteins. Smith (50)(49)(48) classifies the intracellular proteins as: (1) myosin, (2) myogen, (3) globulin X, and (4) myoalbumin. Szent-Gygorgyi (54) changed Smith's classification so that myosin included two fractions, one called myosin and the other called actin. The complex was termed "actomyosin."

A number of intracellular proteins of various origins are often classed together as globulins. Smith (48) states that these proteins are precipitated by reducing the salt concentration of their environment. They also readily undergo denaturation and are peculiarly sensitive to neutral salts. Their state of aggregation is affected by quite small changes in salt concentration.

Von Muralt and Edsall (38) showed that myosin solution had a high viscosity and a strong double refraction of flow. The interpretation placed upon these two experimental properties is that the individual particles of myosin must be somewhat elongated in shape.

Szent-Gygorgyi (54) gives the following properties of myosin. It is a hydrophilic colloid, soluble in water with its isoelectric point at pH 5.3. It has a fairly high but normal viscosity, which indicates that its particles are slightly elongated. Szent-Gygorgyi also notes that these particles have a strong tendency toward association as expressed by the splendid double refraction of flow in aqueous solutions. This double refraction of flow readily disappears as the pH is raised or salt is added in higher concentration.

Myosin (54) has a striking and unique property. Though a hydrophilic colloid, it is precipitated by very small concentrations of neutral salts. For example, 0.025 M KCl suffices for the quantitative precipitation of myosin. If the KCl concentration is raised to 0.1 M, the precipitate dissolves with a strong double refraction of flow. This double refraction of flow disappears if the KCl concentration is raised above 0.3 M. This action of KCl is not specific and is duplicated by NaCl or other neutral salts. These reactions, occurring because of the unequal adsorption of ions, are common to all proteins.

Actin (54) is a hydrophilic colloid with its pI at pH 4.7. It is capable of existing in globular as well as in fibrous form. These forms can be transformed reversibly into each other. The globular-fibrous transformation depends on the presence of ions.

Actomyosin (54) is very hydrophilic and swells in the absence of salts exceedingly. Swelling is prevented by 0.001 M KCl or other neutral salts. If the salt is added to the swollen gel, it becomes turbid and shrinks. If salts are added to a salt-free actomyosin suspension, it precipitates.

Collagen is a fibrous protein found in tendons, muscles, and many parts of the body. Lloyd, Marriott and Pleass (31) in their work with collagen note that water is found bound in association with N- or O-containing groups. It also exists in the free state. The swelling of collagen resembles the swelling of gelatin although the degree is less. It is minimal in the neutral zone, maximum in acid, and has one or more poorly defined maxima in alkaline solution. The swelling is repressed in the presence of salts. Salts cause a thickening and loss of area.

Protein Denaturation and Dehydration

Neurath, Greenstein, Putman and Erickson (39) summarize that recognition of differences in shape characteristics has led to differentiation between corpuscular and fibrous proteins. The former group comprises spherical and moderately anisometric molecules, whereas the latter group includes molecules of rod-shaped and fibrous configuration. Under the influence of certain kinds of denaturing agents, globular proteins may be converted into the fibrous state, whereas fibrous proteins, such as myosin and tobacco mosaic virus, assume a more nearly spherical configuration.

In an investigation on denaturation of proteins in ox muscle juice Finn (15) studied the effects of dehydration. The removal of water up to 78 per cent is accompanied by a change to the acid side of the original pH and further concentration leads to a shift to the alkaline side. Finn (15) found that from pH 7 to pH 6 denaturation is at a constant low level of about 1 per cent. On the acid side of pH 6 denaturation increases regularly until at pH 4.8, 40 per cent of the coagulable nitrogen is precipitated.

The effect of temperature upon hydrogen-ion concentration was also studied by Finn (15). As the temperature was lowered the pH increased in the order of 0.02 units per degree centigrade. In a muscle juice of pH 5.5 at 18°C., the hydrogen-ion concentration was about pH 5.9 at -3°C. and pH

6.0 at -10°C. When freezing began, concentration of the aqueous phase took place, producing a further change in pH.

The role of salt concentration in the denaturation which occurs during freezing and storage was also investigated by Finn (15). Mixtures of potassium and phosphate ions were used, and at pH 6 the denaturation occurring at molar concentrations from 0.4 to 1.0 was in the order of 1 per cent of the total coagulable nitrogen. At higher concentrations there was a gradual increase. At pH 5.2 the denaturation was much greater and came to a maximum at about 0.8 mols.

Moran (36) found the maximum denaturation of muscle proteins occurring at -2° to -3°C. because of the combined effect of the altered pH and salt concentration in the liquid phase of the partly frozen muscle.

Neurath _et_ _al_. (39) state that when myosin is exposed to high temperature, its great susceptibility to super contraction has been ascribed to the presence of fewer and probably more reactive cross linkages.

Neurath _et_ _al_. (39) conclude in their review that denaturation of globular proteins results in a structure similar to that revealed by keratin when it "super contracts," _i.e._, a bundle of disoriented polypeptide chains. They further add that this configuration has been reached in these two instances from opposite ends.

Mirsky (37) has said that the coagulation of myosin in muscle bears a certain resemblance to coagulation of myosin caused by dehydration.

Chick and Martin (13) state that heat coagulation is a reaction with a high temperature coefficient, the reaction velocity of which varies considerably with different proteins and according to the acidity and saline content of the solution.

The Composition of Chicken Breast Muscle

According to Harshaw (22) the composition of the breast muscle of male chickens is:

protein	23.5%
fat	1.12%
ash	1.11%
water	74.6%

Post Mortem Changes in Poultry

Hanson (21) in a study on New York-dressed broilers found that the development of rigor varied widely in individual birds and also in different muscles in the same bird. Another interesting observation was that the time for onset and passing of rigor varies in different muscles of the same broiler carcass.

Smith (47) observed that an animal which struggles violently both before and after stunning goes into rigor sooner than a quiet animal. It seems that considerable lactic acid is developed by the activity prior to killing. Animals very active just before death have a rapid decrease in pH values of the tissues as compared with the pH values of animals killed under anesthetics.

Baker (2) stated that the normal beef animal when killed and passing into rigor forms 0.7 to 1.0 per cent of lactic acid, and cited the fact that 0.9 per cent lactic acid developed while the temperature was falling from 37° to 21°F. in the first 30 hours after slaughter. Obviously the pH fall is closely related to the amount of lactic acid developed.

Changes in Frozen Poultry During Freezing and During Storage

Stewart (52) points out that loss of bloom and freezer burn, caused by desiccation, are two of the most common forms of deterioration in frozen products, but chemical changes such as rancidity may also occur. Changes owing to drying are affected by humidification of freezer, packaging, and temperature.

Stewart, Hanson, Lowe and Austin (53) found by means of microscopic study that both the rate of freezing and time of aging before freezing affected the histological appearance of the muscle fibers. All birds frozen within 2 hours after slaughter at -67.8°C. had vacuoles within the fibers of breast and thigh muscles. These vacuoles were considered to have been the site of ice crystals which had formed in intra-fibrillar freezing. About half of the birds frozen within 2 hours after slaughter at -45.6°C. had vacuoles within the fibers. No intra-fibrillar freezing was found to occur in broilers frozen at -27.8°C. nor in any birds held 18 hours before freezing regardless of the freezing temperature.

Tressler (57) states that uneven desiccation over the surface of the bird produces characteristic light spots called freezer burn. This includes the white pock marking around the feather follicles. Tressler (57) and Birdseye (5) associated desiccation with partial oxidation of fats and some denaturation of protein.

Cook (14) found that when dressed poultry is stored in the frozen state, the loss of bloom during storage depends mainly on the extent of evaporation. Low temperatures and high humidities tend to preserve bloom. In a package lined with a sealed, water-resistant material, such as waxed paper, little deterioration of the bloom was detected during 50 weeks' storage at -13.5°C. (7.5°F.), but if the liner was not sealed, serious deterioration occurred in from 20 to 30 weeks at this temperature.

Cook (14) also studied the storage of various grades of poultry stored in the same types of packages. There was some evidence that the initial bloom was retained longer on the higher-grade birds.

A summary of information on causes of freezer burn is given by Tressler (56). "In general, it can be said that freezer burn is caused by the uneven desiccation of cold-stored poultry. Certain changes in the fats and proteins of the tissue immediately underneath the desiccated areas probably occur simultaneously with the drying out of the tissues. The proteins become denatured and do not easily take up (rehydrate) the water which they have previously lost. The fats being exposed to the air take up oxygen and slowly become rancid."

In wrapping lamb kidneys for frozen storage, Barnicoat (3) indicates complete success in preventing "store-burn" by using a moisture-proof cellophane. Other wrappers ("butchers'" paper and vegetable parchment) were unsatisfactory.

Brady, Frei and Hickman (7) found that the evaporation rate of slow-frozen meat was higher than the evaporation rate of quick-frozen meat during storage.

In 1907, Pennington (41) described the drying effect of cold storage on poultry. She found that the skin of birds stored at 15°F. was somewhat dried in 10 months, and the breast muscles were very badly dried in three years with accompanying rancidity and oxidation of fat. In general, it can be understood readily that desiccation increases with storage time.

Hiner, Madsen and Hankins (24) found that freezing meat slowly results in more drip loss during defrosting than does rapid freezing of meat. Freezing at 18°F. resulted in the formation of large interfibrillar ice areas which pushed the fibers together into groups. At this temperature no intra-fibrillar ice crystals and ice areas were observed. The size of ice crystals and ice areas between fibers decreased as the freezing temperatures were lowered. At 0°F. some fiber-wall damage and intra-fibrillar freezing were observed. Beginning at -10°F. enough ice was frozen within the fiber that the fiber itself was ruptured. At -114°F. nearly every fiber was ruptured and was split longitudinally sometimes into several sections.

Sair and Cook (44) gave pH values for chickens stored at 0°C. as follows:

Changes in pH of Chicken Muscle During Storage at 0°C.

Time after slaughter in hours	pH of whole muscle -- normal bird
0.5	7.0
1.5	6.5
4.0	6.2
6.0	5.6
24.0	5.5

Proteolytic enzymes may be responsible for the change of proteins to amino acids. Baker (2) suggests that when the pH rises again to 6.2 the meat has become deteriorated.

Palatability Changes During Storage

Stewart _et al_. (53) explain that palatability changes of frozen poultry involve two factors, flavor and juiciness of the meat. The lack of juiciness is associated with a "dryness" in texture of frozen and stored poultry meat. This dryness is most pronounced in the breast muscles, and is more noticeable in some birds than in others.

Lowe (28) has stated that there is a tendency for the muscles of some frozen birds to become powdery, dry, and very tender during storage. She believes that this change might be due to enzyme action.

Bound Water Analysis of Protein

Bound water present in biological materials is defined in terms of the experimental technique by which it is measured. Gortner (18) has outlined thirteen different techniques that might be used in bound water analysis.

Bound water may be defined as that water which remains unfrozen at some specified temperature below zero such as -20°. Several techniques are based upon this definition.

1. The calorimetric method was developed by Rubner (43) and also by Theones (55). Essentially it is based upon the amount of water remaining unfrozen at temperatures below $-20^{\circ}C.$, and it involves the amount of heat absorbed by a

system as the temperature is raised from -20°C. to 1°C. If allowance is made for the specific heats and for the fact that each gram of ice absorbs 80 calories of heat as it melts, the amount of water frozen at -20°C. can be calculated. This amount is then subtracted from the total water to give the bound water.

2. The dilatometer method consists of measuring the expansion of a system upon lowering the temperature through the freezing point. Jones and Gortner (20) used this method in studying the free and bound water of gelatin gel.

Kistler (26) and Blanchard (6) have criticized the above techniques on the grounds that water has a tendency to supercool to -20°C. or lower without freezing. Such supercooled water would be calculated as bound water.

Bound water has also been defined as the amount of water in a system which is not available to act as a solvent. Several techniques involve this definition.

1. The cryoscopic method was used a great deal by Gortner (19). The freezing point of the system containing the hydrophilic substance is determined. A certain amount of a solute, such as glucose, is added, and the freezing point is redetermined. The total amount of water present and the fact that a molar solution of glucose has a freezing point 1.86° below that of water being known, the concentration of the glucose can be calculated. The concentration based upon

the total amount of water present is known. The difference between the actual and calculated concentration of glucose gives the amount of water which was bound to the hydrophilic colloid and not available as a solvent.

2. The vapor pressure lowering of water has been used as an indication of the amount of bound water in a hydrophilic colloid. Hill (23) used it in determining the state of water in muscle and blood. The method developed by Hill is very delicate and is based upon a measurement of the temperature change experienced when water evaporates, the rate of evaporation being proportional to the vapor pressure.

A simple direct method for measuring the vapor pressure of water in hydrophilic substances has been described by Briggs (8). The apparatus used is called an isotenoscope. The vapor pressure is measured in centimeters of mercury by means of a mercury manometer. Briggs measured the vapor pressure of water associated with moist samples of casein, agar, fibrin, and cellulose.

In a second paper Briggs (9) discusses some of the theoretical aspects of bound water. In order to define bound water it is necessary to specify the activity below which water is said to be bound. The activity of water is 0.822 at -20°C. If the temperature of a colloidal system is lowered to -20°C. and allowed to remain until equilibrium has been reached, all the water whose activity is unity down to

0.822 will freeze and will be calculated as free water. The remaining water with an activity of 0.822 and lower does not freeze and is calculated as bound water. Of further interest is the fact that Briggs (9) also emphasizes the important roles played by electrolytes associated with the colloid.

Vapor Pressure Isotherms

Makower and Myers (35) used the vapor pressure method to determine moisture content of dehydrated vegetables. Determinations could be made in two hours on dehydrated foods that were at moisture equilibrium. Measurements were limited to the vapor pressure of water at room temperature and to a maximum moisture content of 15 per cent in carrots or 8 per cent for eggs.

The dehydration of hydrophylic materials by means of an isotenoscope is obviously an adsorption process in reverse, *i.e.*, desorption. A plot of moisture content against relative vapor pressure at constant temperature results in a vapor pressure isotherm.

Freundlich (17) proposed an empirical isotherm to describe the relation between the amount of solute adsorbed and its concentrations. He proposed a simple equation for the isotherm. Langmuir (27) also was able to derive an adsorption equation. He equated the rate of evaporation of a gas from a solid surface to the rate of condensation.

Bull (12) found that the adsorption of water vapor on a porous solid such as silica gel or on solid proteins usually follows a typical course. The plot of the amount of water adsorbed against the aqueous vapor pressure gave an S-shaped curve.

Brunauer, Emmett and Teller (10) proposed an equation for S-shaped adsorption curves which describes the adsorption of vapors on free surfaces. They generalized Langmuir's adsorption theory to include multi-layer adsorption.

The Brunauer, Emmett and Teller equation is known to fit only the lower 50 per cent of the adsorption curve. Pickett (42) derived an equation that could be used over the full range of relative vapor pressures.

Makower and Dehority (34) found that the sorption isotherms for five vegetables were S-shaped and characterized by an inflection point in the neighborhood of 5 per cent moisture content.

In studying the data of Bull (12) and Shaw (45), Pauling (40) observes that the adsorption of water by proteins is in considerable degree interpreted on the assumption that the initial process is the attachment of one water molecule to each polar amino acid side chain. Pauling (40) adds that these data indicate that peptide, carbonyl, and imido groups usually do not bind water because of their mutual interaction by hydrogen bond formation. However, water is bound by carbonyl groups not coupled with imido groups by means of hydrogen bonds.

METHOD OF PROCEDURE

Preparation of Roasters for Storage

Male New Hampshire roasters, 60 in number, were killed and used for the experiment. Two birds were prepared each day until all had been put into frozen storage.

To kill the chickens, the necks were stretched and broken. The birds were hung by both legs immediately and allowed to flutter until quiet. They were then scalded by dipping in hot water (57.7°C., 136°F.) for 30 seconds. The feathers were pulled off by hand and the heads and legs removed. The birds were eviscerated and washed inside and outside with cold running tap water. They were next wrapped in waxed paper and kept in a refrigerator at 1.6°C. (35°F.) for 24 hours. Then the two birds were removed from the refrigerator, washed again, and a small sample removed from the anterior part of the breast muscle without rupturing the skin. This was accomplished by pushing back the skin at the neck. Each bird was wrapped in cellophane paper and the wrapping sealed with Scotch cellulose tape.

The roasters were labeled according to series and storage temperature and placed in a sharp freezing unit held at -34.4°C. to -37.2°C. (-30°F. to -35°F.), where they were left for 24 hours.

Frozen Storage of Roasters

For the statistical design the 60 roasters were divided into three groups called Series A, B, and C. After freezing, each group was subdivided, half of the roasters being stored at -12.2°C. (10°F.), the other half at -23.3°C. (-10°F.).

In series A the roasters were stored for 9 months before cooking. Relative vapor pressure tests were made upon samples of raw muscle before freezing, on the raw muscle after storage for 9 months, and upon the cooked muscle.

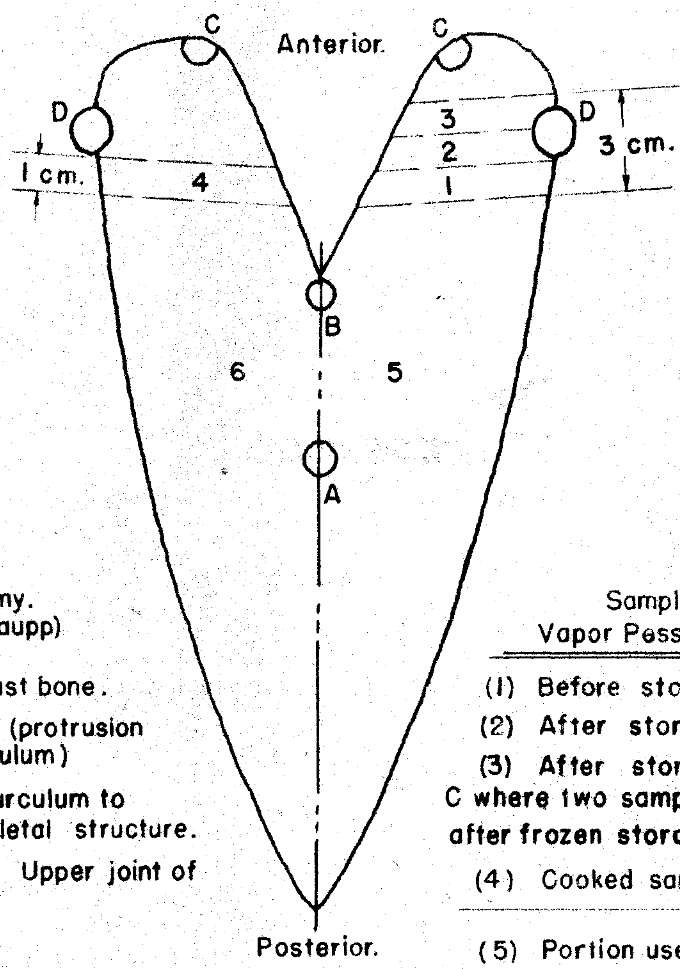
Series B was similar to series A except storage was for 6 months.

The storage time for series C was 9 months. Series C differed from series A as follows. In addition to the relative vapor pressure tests upon the raw breast muscle before freezing, on the raw muscle after 9 months' storage, and after cooking, a test was made on the raw muscle at the end of 6 months' storage.

Location of Samples in Breast Muscle of Roaster

The anatomical location of the samples taken before freezing, after storage, and after cooking for the relative vapor pressure tests (R. V. P.) is shown in figure 1. The nomenclature is by Kaupp (25).

The raw samples were cut crosswise from the left side



Anatomy.
(After Kaupp)

(A) Keel of Breast bone.

(B) Hypocledium (protrusion of furculum)

(C) Joining of furculum to main skeletal structure.

(D) "Wing joint" Upper joint of humerus.

Samples for
Vapor Pessure Analysis.

(1) Before storage.

(2) After storage.

(3) After storage, as in Series C where two samples were removed after frozen storage.

(4) Cooked sample.

(5) Portion used for palatability scores.

(6) Portion used for shear for press fluid tests.

Pectoralis Major.

Fig. 1. Location of the samples taken from the roaster breast muscle for use in the vapor pressure analysis.

of the pectoralis major and are shown as (1), (2), and (3) in figure 1. The cooked sample (4) was taken on the right side. Samples (1) and (4) were taken about 3 cm. anterior to the hypocledium protrusion of the furculum (B). All of these samples were about 1 cm. in thickness.

All of the samples except those for 6 months' storage in series C were removed from underneath the skin by pushing back the skin where the neck had been removed. After removal of the sample the skin was pulled over the cut surface to prevent desiccation.

In series C (6-, 9-month) samples had to be sawed from the frozen bird for the 6-month storage test. A portion of the skin was therefore removed.

All of the samples were placed in small sample bottles and R. V. P. tests started at once after removal of the sample from the bird.

The locations of other samples mentioned in this study are also shown in figure 1. These include those used for palatability scores and those used in determining press fluid.

Preparation for Cooking

Two roasters were removed from the frozen storage locker each day. One had been stored at -12.2°C. (10°F.), and the other at -23.3°C. (-10°F.). They were allowed to thaw partially at room temperature for approximately three hours.

Then they were placed in the refrigerator at 1.6°C. (35°F.) for 20 hours, after which time a sample from the breast muscle of each roaster was removed for R. V. P. tests.

After removal of the R. V. P. sample the roasters were rewrapped in cellophane and kept in the refrigerator for another 4 hours. The roasters were then placed in another refrigerator at 4.0°C. (39.2°F.) for an additional 16 hours, after which time they were removed for cooking.

A fresh control roaster was killed in the manner described for the roasters that had been killed for frozen storage. The control was kept approximately 24 hours in the refrigerator at 4°C. (39.2°F.).

Cooking of Roasters

The two roasters that had been kept in frozen storage were unwrapped, weighed, and the appearance of the carcass noted. Also the control roaster was prepared for cooking.

Doneness of the cooked roaster was determined by means of a thermometer inserted in the right thigh.

Each of the three roasters was placed breast down on a rack in an oval-shaped baking pan (11x8x1½ inches). Each roaster was baked in a separate gas oven at 150°C. (302°F.). The temperature of the oven and the temperature of the roaster were recorded every 15 minutes. When the internal temperature of the thigh muscle reached 85°C. (185°F.), the roaster was removed from the oven.

Further information regarding cooking of the roasters, palatability scores, and objective tests are given by Wills (58).

Palatability Scores

Aroma, flavor, tenderness, and juiciness were the four factors scored for palatability. Juiciness was the only factor considered in this study. Juiciness scores could vary from 0 to 10, 10 being the high score. The judges were given the breast muscles of the left side and the left thigh for scoring. The roasters were scored soon after removal from the oven. Each judge was given the same anatomical portion of the breast muscle from day to day. The average scores of the four judges are given in table 27 of the appendix. After removal of the samples for scoring, the remaining part of the carcass was placed in the refrigerator about 2 hours, before determination of the objective tests on the right breast and thigh muscles.

Press Fluid

Three samples for press fluid determination were taken from the right side of the breast muscle immediately posterior to the location of the vapor pressure samples.

(See fig. 1.) Each sample (1.75-2 gm.) was weighed, wrapped in absorbent cloth, subjected to 250 pounds pressure for five minutes, and reweighed. The difference between the two weights, divided by the original weight, gave the per cent press fluid.

Preparation of Samples for Vapor Pressure Analysis

The male parts of standard-taper (14/35) pyrex joints were closed at one end and used as tubes to hold the samples during desiccation in the vapor pressure apparatus. The tubes were numbered, cleaned in distilled water, cleaned in gasoline, and then weighed on an analytical balance to 0.0002 gram.

Small cubical particles from 1/2 to 3/4 cm. on a side were cut on waxed paper from the samples that had previously been removed from the roaster. About three particles were pushed down into a tube, and duplicate tubes containing sample particles were prepared from each roaster. Handling of the tubes was done by means of a clean cloth.

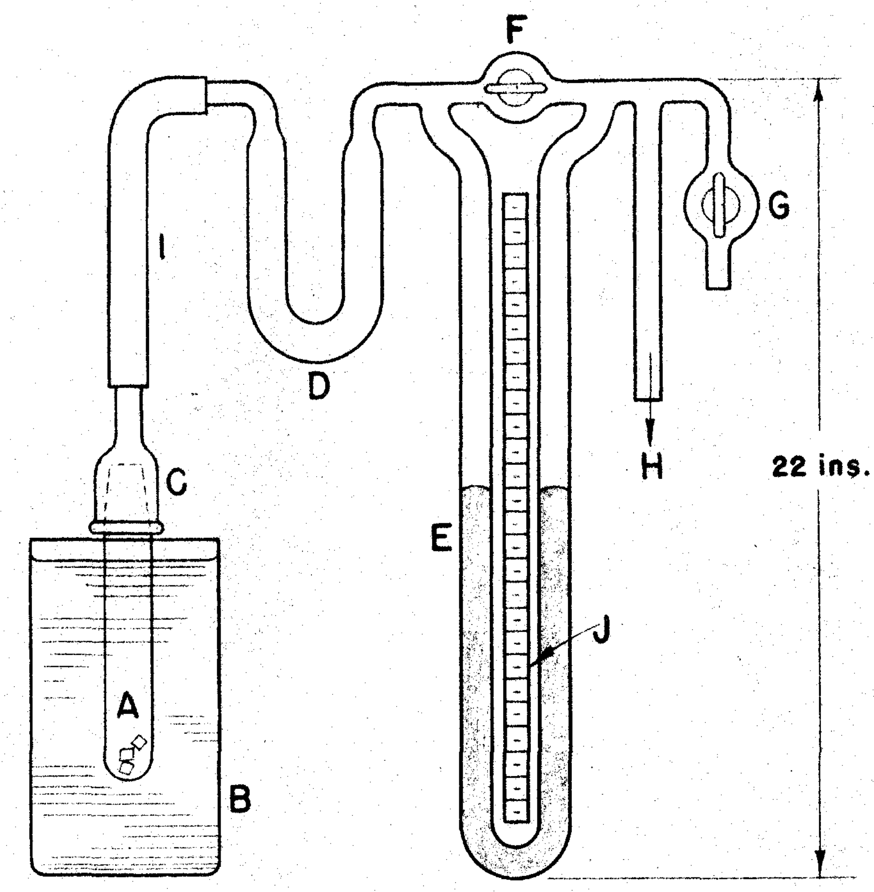
The tube and contents were weighed and recorded. The tubes were then inserted over halfway into a water bath kept at a constant temperature of 27.5°C. (81.5°F.). They were allowed to remain there until the samples had reached temperature equilibrium, a time period of at least 10 minutes. Then the first vapor pressure reading was made.

Vapor Pressure Apparatus

An isotenoscope type of apparatus shown in figure 2 was used for measuring the vapor pressures. It consisted chiefly of pyrex glass. Mercury was used in the manometer. The difference in mercury levels in this manometer gave the vapor pressure in millimeters. In figure 2, part I consisted of heavy-walled rubber tubing. Part C was the female part of a standard-taper (14/35) pyrex joint. Into this part of the joint (part C) the previously mentioned desiccating tubes were inserted. Part D served as a moisture trap.

A Cenco-Hyvac vacuum pump was attached at H (fig. 2). A mercury trap was inserted in the line between H and the vacuum pump.

The accompanying water bath was kept at constant temperature by means of a thermostat, two heating blades, a cone-type stirrer, and tap water running through a coiled copper tube. These control devices kept the temperature of the bath at 27.5°C. ±0.4°C. A signal light was wired in series with the thermostat to call attention to any possible extreme fluctuation of bath temperature. A thermometer graduated to 0.1 degree centigrade was used in the bath.



EXPERIMENTAL APPARATUS.

Fig. 2. Apparatus used in vapor pressure analysis.

A. Sample tube with sample.
B. Constant temperature (27.5°C.) water bath.
C. 14/35 Standard taper pyrex joint.
D. Moisture trap.
E. Mercury manometer.
F, G. Stop cocks.
H. To vacuum pump.
I. Heavy-walled rubber tubing.
J. Vapor pressure scale in millimeters.

Reading of Vapor Pressure

Using figure 2 as a guide, a desiccating tube, A, containing the sample, was greased at the top with Lubriseal (a grease used for high-vacuum sealing). The tube was then inserted into C (female pyrex joint). Valve G was closed and valve F allowed to remain open. These valves were also greased with Lubriseal. The vacuum pump was turned on, and the entire system was allowed to be evacuated for 1 minute. At the end of a minute a dry ice-alcohol bath was placed around the trap D, and allowed to remain for 1 minute. This procedure caused a freezing of the moisture coming from the sample in the desiccating tube A.

At the end of the 1-minute moisture-trapping period valve F was closed, and the dry ice-alcohol bath was removed. The trap was allowed to warm up slightly and then a warm-water bath was placed around it. From the time that valve F was closed until the two mercury levels were read, 4 minutes elapsed. This might be considered the equilibration period, at the end of which the vapor pressure was read. Vapor pressure readings were made within a 2-per cent experimental error.

After the vapor pressure was read on a sample, the Lubriseal was removed from the outside by the use of gasoline and the tube was wiped dry with a clean cloth. The tube and contents were weighed on an analytical balance to 0.0002 gram and the weight recorded. This procedure was followed with the exception that the initial vapor pressure reading made on a sample followed the weighing process instead of preceding it as in all other cases.

In order to obtain a correction factor the vapor pressure reading of water was taken each day. Several drops of distilled water were lowered into one of the desiccating tubes. The same evacuation process and equilibration time were used as for a sample of roaster breast muscle.

After the initial vapor pressure recording, the four samples being studied were inserted into a unit containing four female pyrex joints and attached to the vacuum pump. Then this unit was lowered into the water bath and the entire system evacuated for about 30 minutes. At the end of this time a vapor pressure reading was taken and recorded, and a weighing was made and recorded.

The procedure for evacuation was repeated and another reading made from 20 to 30 minutes later. The corresponding weight was obtained. Finally, the sample tubes were inserted into the female joint unit and allowed to evacuate over night at 27.5^{o}C. (81.5^{o}F.). The next morning they were always evacuated from 0 to 0.5 mm. vapor pressure at 27.5^{o}C.

Four vapor pressure readings and corresponding weights were obtained on each sample. Duplicate samples gave a total of eight readings per roaster for each condition of storage.

Preliminary Experiment

Vapor pressure isotherms were plotted from data on a heterogeneous group of broilers held in frozen storage for different storage temperatures. The vapor pressure studies done as a preliminary to the work discussed in this study, were done under similar experimental conditions. The vapor pressure isotherms plotted from a random grouping of 12 birds indicated the type of curve that could be expected as a result of vapor pressure studies. The isotherm for these data is shown in figure 3. It was apparent that the isotherm was a typical S-shaped sorption curve. Data from a single one of these birds is shown in figure 4.

Calculations on Data

From the data collected it was possible to calculate the original sample weight, the amount of moisture lost under vacuum, and the weight of the dry sample at 27.5°C. (81.5°F.). The amount of moisture lost during desiccation was considered to be the per cent water in the sample. The grams of water divided by the grams of dry sample was calculated.

The vapor pressure readings were converted to relative vapor pressure readings (R. V. P.). This was done by dividing the millimeters of mercury reading for the roaster sample by the vapor pressure reading in millimeters of mercury for water

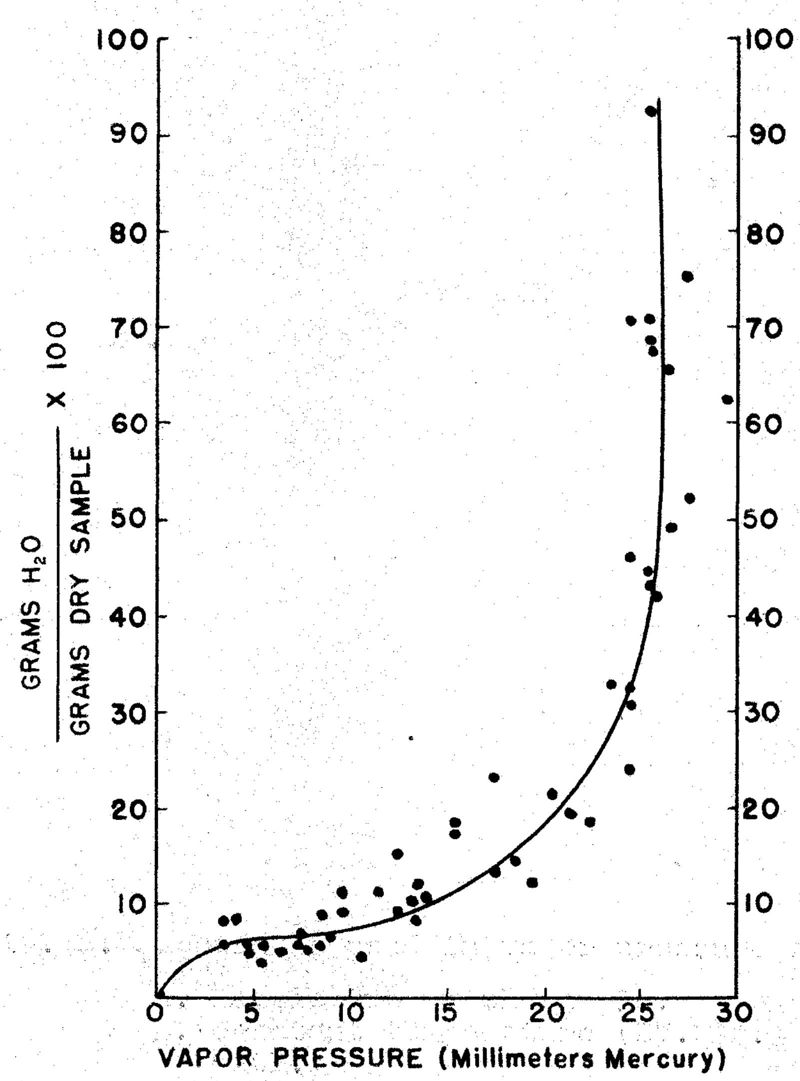


Fig. 3. Typical S-shaped desorption isotherm. Data from preliminary vapor pressure analysis of cooked breast muscles of a heterogeneous group of 20 broilers. The isothermal temperature was 27.5°C.

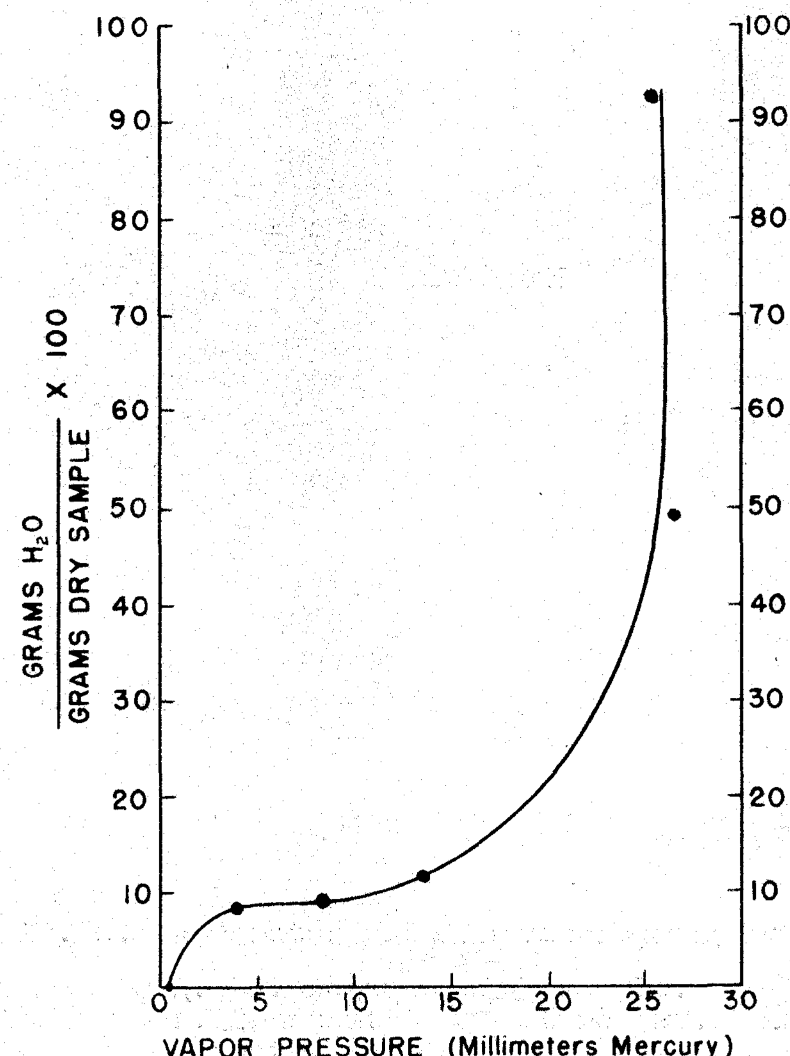


Fig. 4. **Typical S-shaped desorption isotherm. Data from vapor pressure analysis of cooked breast muscle of a single broiler, with the temperature of the water bath at 27.5°C. (Preliminary study)**

at 27.5°C. (81.5°F.). The vapor pressure reading for water was not always the standard 27.53 mm. at 27.5°C., but changed with room temperature variations (figure 5).

The R. V. P. readings plotted against the corresponding grams of water/grams of dry sample were represented graphically as vapor pressure isotherms. Such an isotherm can be seen in figure 6.

Room Temperature Correction on Vapor Pressure Readings

The room temperature varied from day to day. Therefore a vapor pressure test of water was made each day. The actual R. V. P. for each reading on the samples for one day was divided by the vapor pressure of water as found for that day. This corrected the R. V. P. readings for fluctuations in room temperature. A plot of room temperature against the vapor pressure of water which was kept in a constant temperature bath of 27.5°C. is shown in figure 5. A standard table for water vapor pressures at different temperatures was consulted. The vapor pressure of water at 27.5°C. was 27.53 millimeters.

Analysis of Data

As has been described previously, the 60 roasters were divided into series A (9 months' storage), series B (6 months' storage), and series C (6-month test, 9 months' storage).

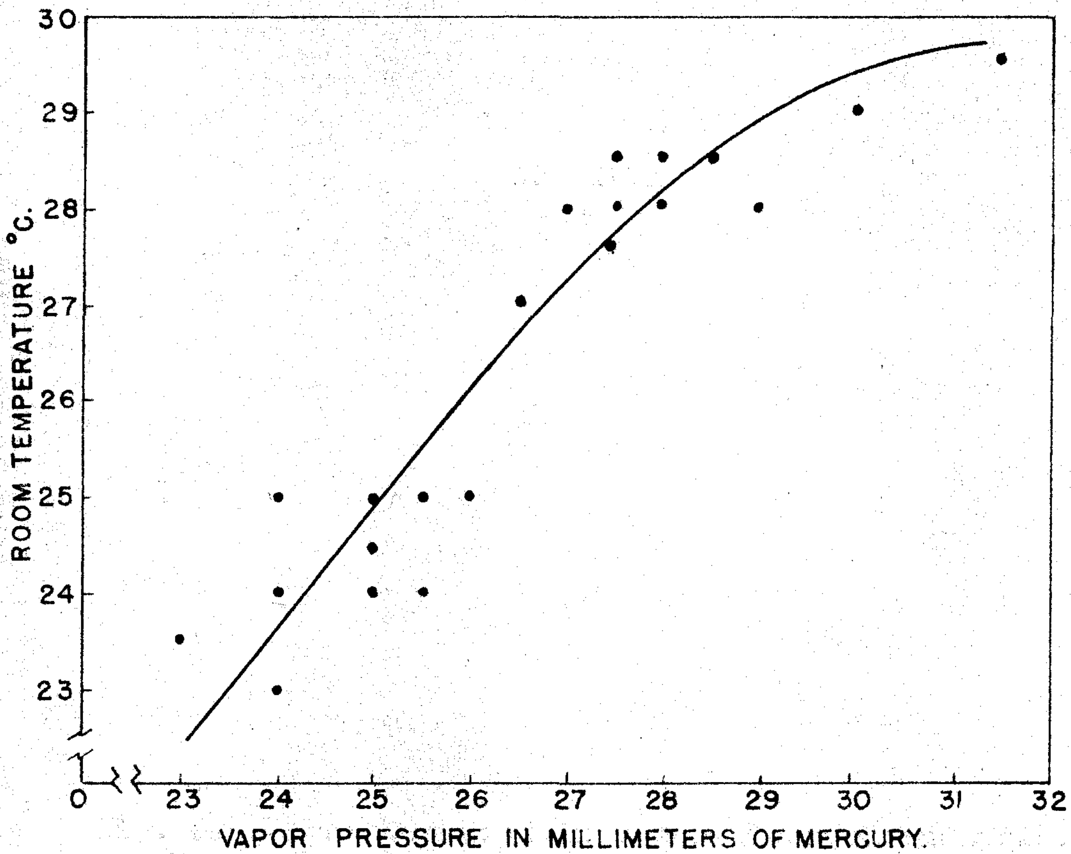


Fig. 5. Effect of room temperature on the vapor pressure of water at 27.5°C. These observations are for a period of 22 days.

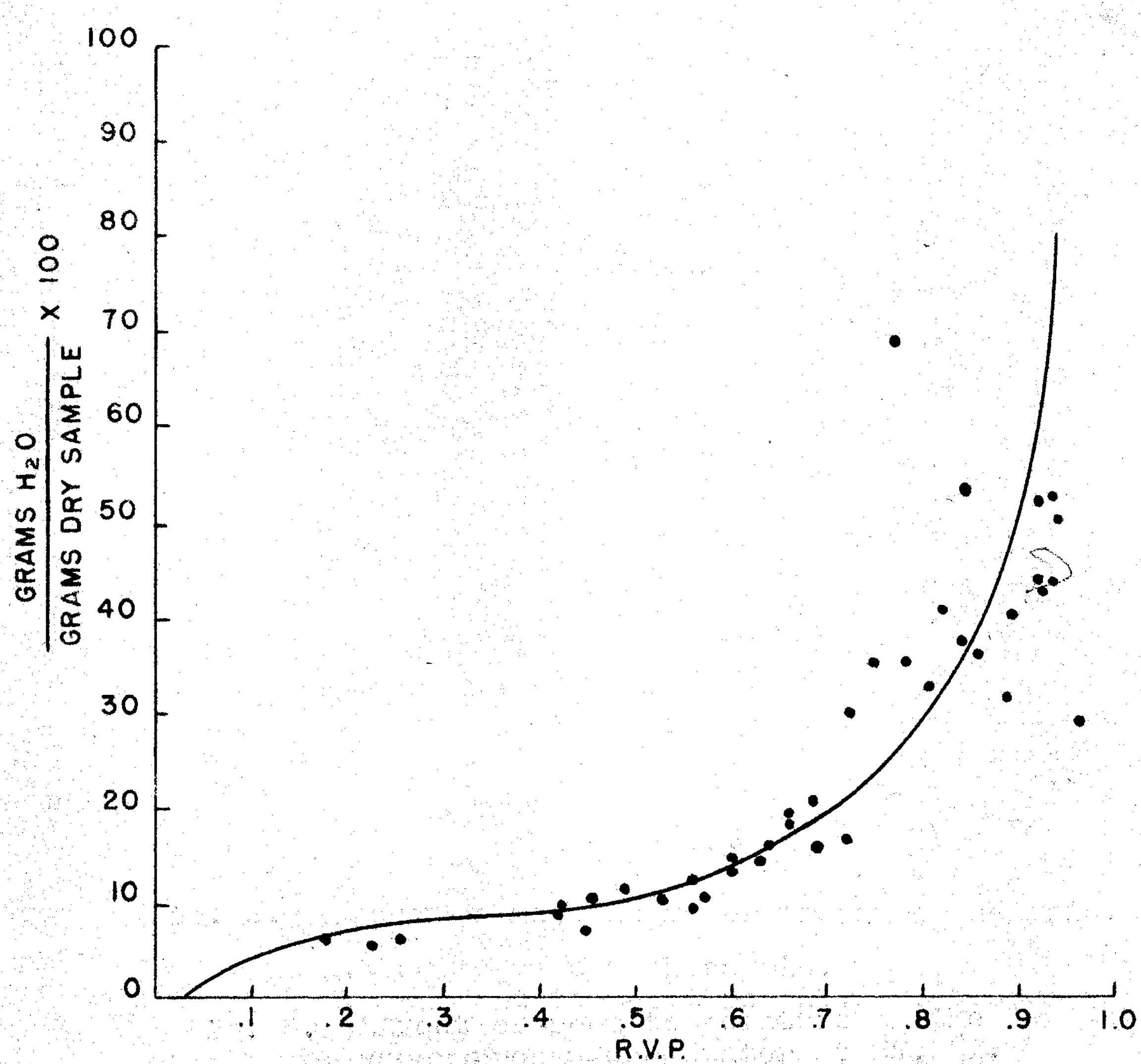


Fig. 6. Relative vapor pressure isotherm of uncooked breast muscle samples removed after 6 months' storage at -12.2°C. (10°F.).

Covariance analysis as outlined by Snedecor (51) was used to compare the data.

It was adequate to apply the simple adsorption equation developed by Freundlich (17) in order to analyze the data. His equation is

$$(1) \qquad \frac{a}{m} = kC^{\frac{1}{n}}$$

Equation (1) may be converted to the logarithmic form:

$$(2) \qquad \log \frac{a}{m} = \log k + \frac{1}{n} \log C$$

Values in this experiment corresponding to the terms of equation (2) were:

$$\log \frac{a}{m} = \log \frac{\text{grams } H_2O}{\text{grams dry sample}}$$

$$\log k = \text{intercept on y-axis}$$

$$\frac{1}{n} = \text{the slope of the regression line}$$

$$\log C = \log \text{R. V. P.}$$

$$\text{x-axis values} = \log \text{R. V. P.}$$

$$\text{y-axis values} = \log \frac{\text{grams } H_2O}{\text{grams dry sample}}$$

The data for the vapor pressure isotherms were converted to logarithms and found to be in the third quadrant. Only the data of the vapor pressure isotherms included in the range of 40 R. V. P. to 100 R. V. P. were plotted, and 100 R. V. P. was excluded. Any values for grams H_2O/grams dry sample exceeding 1.0 were not used. The ordinates of the mean point and the slopes were obtained and the regression lines drawn. The intercepts of the regression lines upon the y-axis were considered to be the most indicative factor of the analysis. No test of significance on intercepts was available.

A simple correlation study was made between the palatability scores and per cent water in the cooked samples.

RESULTS

Vapor Pressure Isotherms

A plot of grams water/grams dry sample against R. V. P. gave a typical S-shaped isotherm, as shown in figure 6. This isotherm represents data from 10 different birds stored at -12.2°C. (10°F.), duplicates being made for each bird. In the upper 50 per cent of the R. V. P. range, these data show a high variation between birds and occasionally between samples. A typical plot of grams water/grams dry sample against R. V. P. for a group of 10 roasters is also shown in figure 6. Since the plotted isotherms for all groups of 10 roasters were very similar in character, the plot of only one group is offered here. Data used for plotting other isotherms appear in tables 1-20 in the appendix.

When the average vapor pressure isotherms for the same series for different lengths of storage time were compared, results such as shown in figure 7 were typical. These vapor pressure isotherms are for the roasters of series A, stored 9 months at -12.2°C. The data curves for the vapor pressure studies of the same 10 birds, before storage, after 9 months' storage, and after cooking are shown. It may be observed that the R. V. P. varies at the same moisture level in the

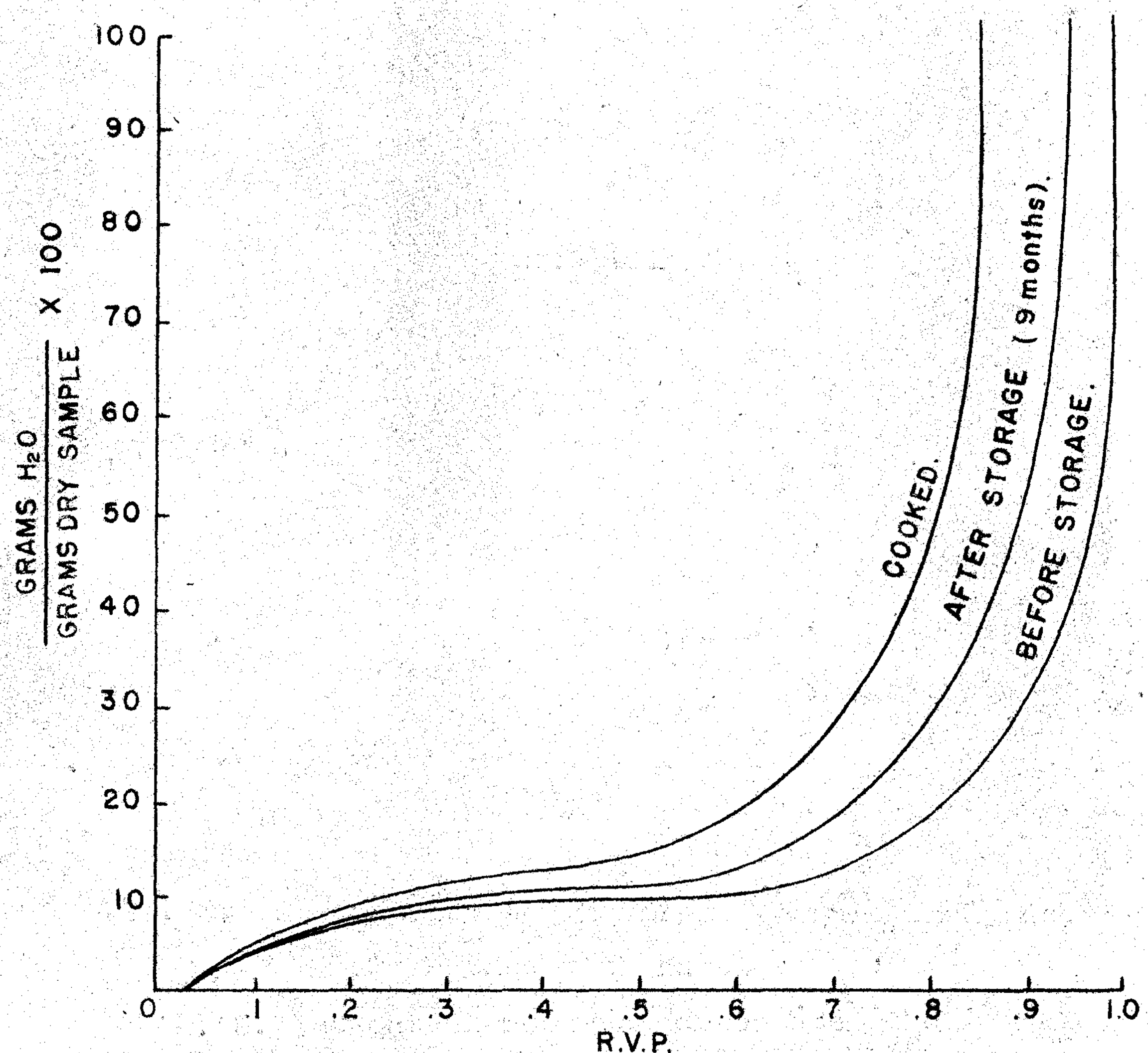


Fig. 7. Typical vapor pressure isotherms of roaster breast muscle. Each isotherm is an approximate average of R. V. P. data for 10 roasters of the A series stored 9 months at -12.2°C. (10°F.). Tests were made before freezing and storage, after 9 months' storage, and after cooking.

upper half of the R. V. P. range for the three different isotherms shown. These R. V. P. values for each curve become progressively lower in samples taken before storage, samples taken after 9 months' storage, and cooked samples. In the same series A, the curves for the group of roasters stored at $-23.3^{o}C.$ $(-10^{o}F.)$ are similar to those shown in figure 7.

Series C was similar to series A in storage temperature and time except that samples were removed from the roasters for testing at the end of 6 months' storage, and the roasters continued in storage for a total of 9 months. The isotherms for the roasters of group C which were stored at $-12.2^{o}C.$ $(10^{o}F.)$ are shown in figure 8. The values for the upper portion of the R. V. P. range for the two different storage times involved become progressively less with the vapor pressure treatments on samples before storage, after 6 months' storage, after 9 months' storage, and after cooking.

The 6 isotherms representing average data of series B show the same trends as series A and series C with one exception. The B series, stored 6 months at $-12.2^{o}C.$ and $-23.3^{o}C.$, shows an exception in the group of birds stored at $-23.3^{o}C.$ In this group the R. V. P. averages for the upper portion of the R. V. P. scale were reversed in the two tests made before storage and after storage. This matter is discussed later.

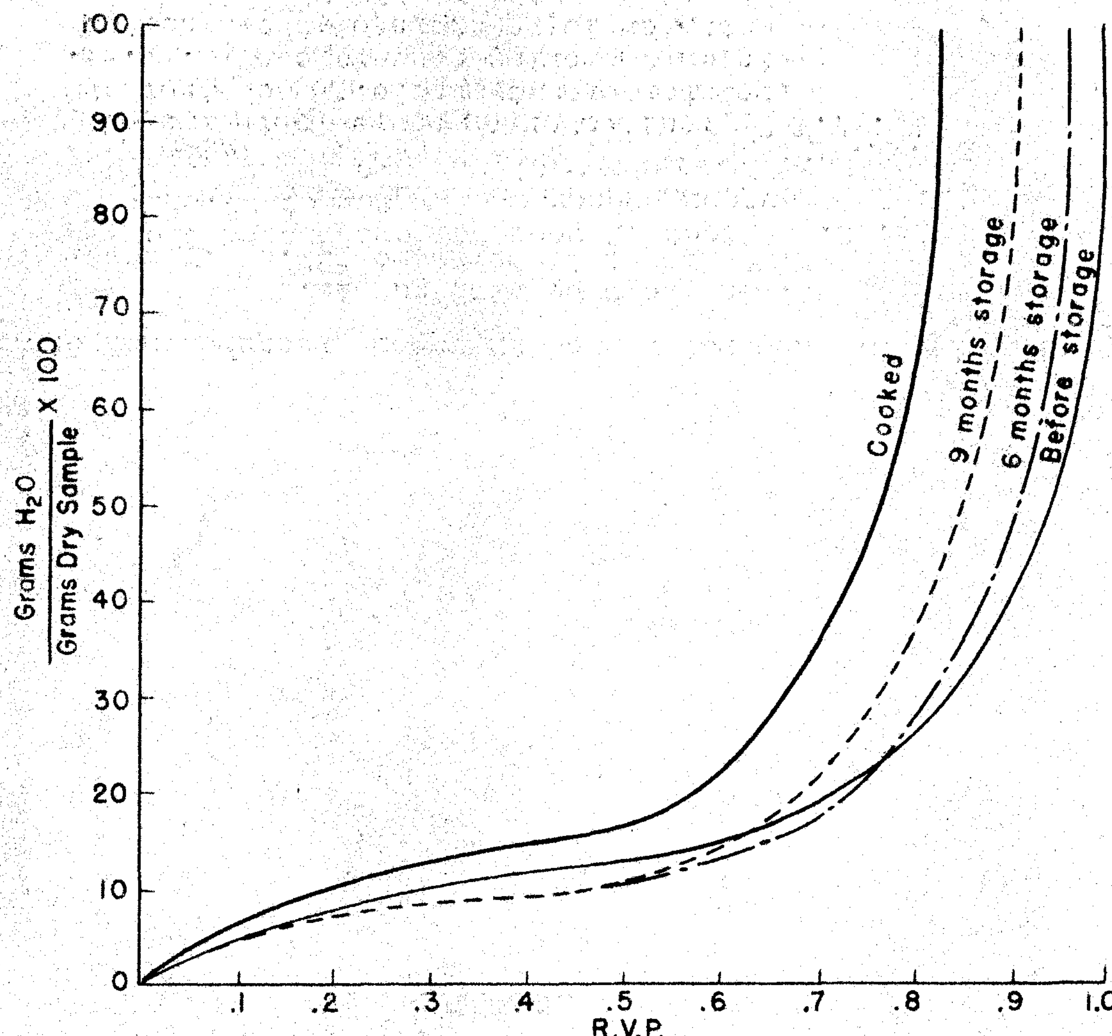


Fig. 8. Typical vapor pressure isotherms of breast muscle. Each isotherm is an approximate average of R. V. P. data for 10 roasters of the G series stored 9 months at -12.2°C. (10°F.). Tests were made before storage, after 6 months' storage, after 9 months' storage, and after cooking.

Application of Freundlich's Adsorption Equation

When the logarithms of each set of axes shown in figure 6 were used as a new set of axes and the data of the isotherm in figure 6 replotted as logarithms, there was definite linearity as shown in figure 9. The data fell into the fourth quadrant and the intercept of the regression line on the y-axis became -0.256. (See appendix table 28.)

Covariance Analysis on Vapor Pressure Data

Each of the regression lines shown in figure 10 represents data from 10 roasters analyzed under the condition indicated on the line. The data of series A are shown in figure 10. In the group stored 9 months, the y-intercepts (log grams water/grams dry sample) progress toward the origin for each type of sample. Specifically, for -12.2°C. (10°F.) they are:

before storage	-0.505
after 9 months' storage	-0.260
after cooking	-0.040

(Appendix table 28.) For group stored at -23.3°C. (-10°F.) of series A the y-intercepts are:

before storage	-0.440
after 9 months' storage	-0.295
after cooking	-0.000

The point 0.000 represents the origin.

The log-log plot of the data for the B series (stored

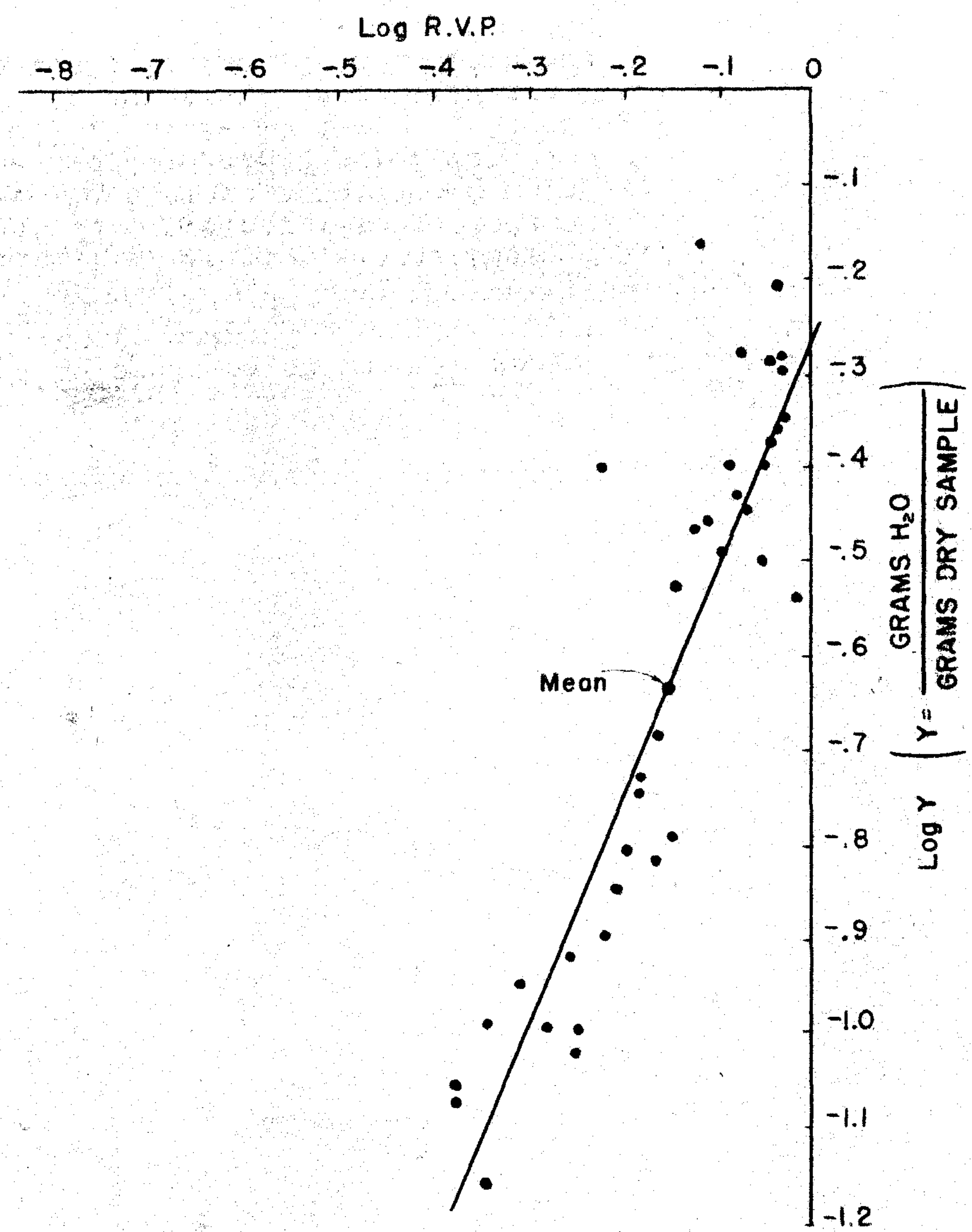


Fig. 9. Typical regression line for data plotted as logarithms. The scatter of points, the mean point, and the slope and y-intercept of the regression line are indicated. These data are from C series on samples removed after 6 months' storage at -12.2°C. (10°F.). The regression line lies in the third quadrant.

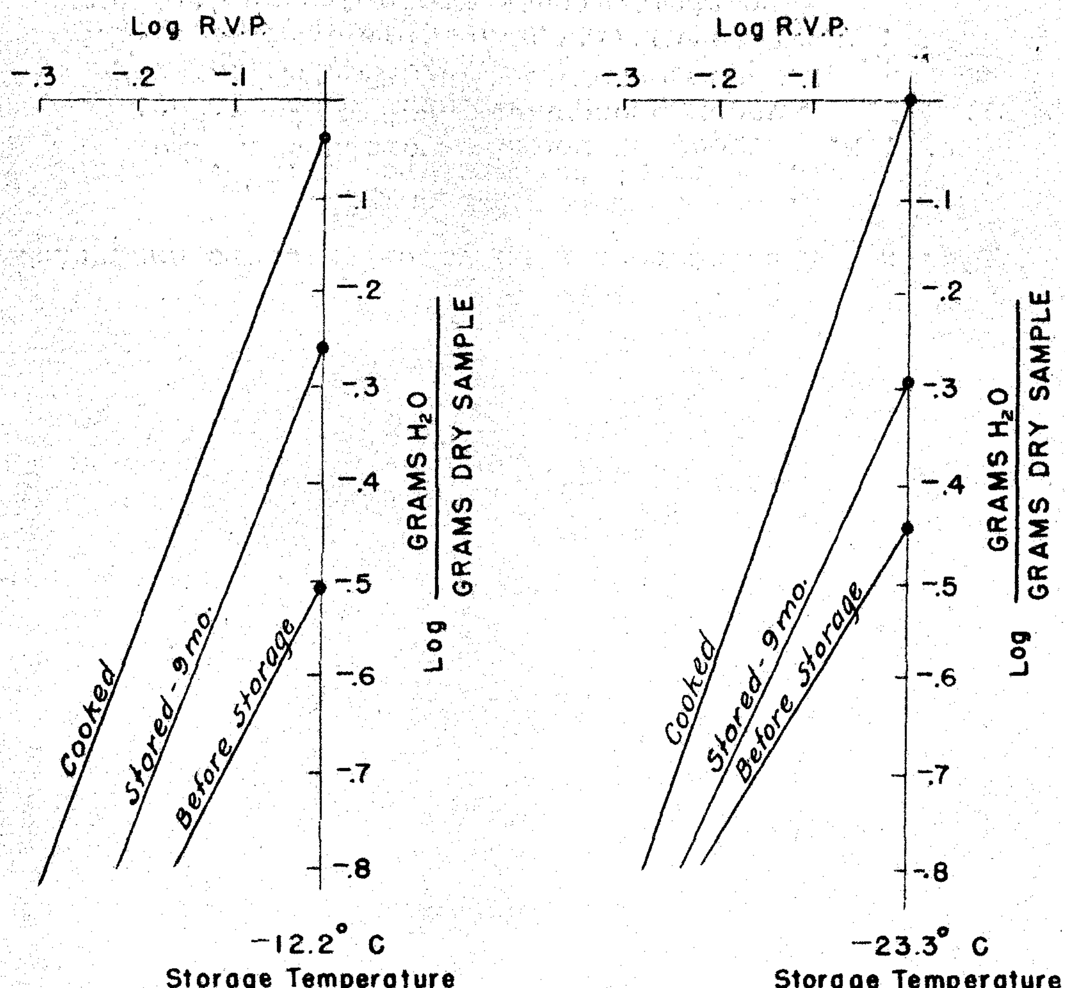


Fig. 10. Covariance analysis of data for R. V. P. isotherms. These data were obtained from the A series of roasters stored 9 months at -12.2°C. (10°F.) and -23.3°C. (-10°F.). The data include the logarithmic regression lines resulting from vapor pressure analysis of breast muscle samples removed before freezing, after 9 months' frozen storage, and after cooking. As the y-intercept approaches the origin, more waterbinding is evident.

6 months at -12.2°C. (10°F.) and -23.3°C. (-10°F.) is given in figure 11. As shown in table 28 in the appendix, the specific y-intercepts of the regression line for -12.2°C. are:

before storage	-0.526
after 6 months' storage	-0.416
after cooking	-0.160

For the storage temperature -23.3°C. the intercepts are:

before storage	-0.541
after 6 months' storage	-0.627
after cooking	-0.189

The log-log plot of data for the C series is shown in figure 12, and the following regression line y-intercepts resulted. For the 10 birds stored at -12.2°C, the intercepts are (appendix table 28):

before storage	-0.503
after 6 months' storage	-0.256
after 9 months' storage	-0.145
after cooking	-0.095

For the 10 birds stored at -23.3°C. the intercepts are:

before storage	-0.478
after 6 months' storage	-0.355
after 9 months' storage	-0.200
after cooking	-0.060

A general summary of all regression line intercepts on the y-axis (log grams water/grams dry sample) is given in figure 13. The length of the line shows the distance of the y-intercept from the origin. This value is negative.

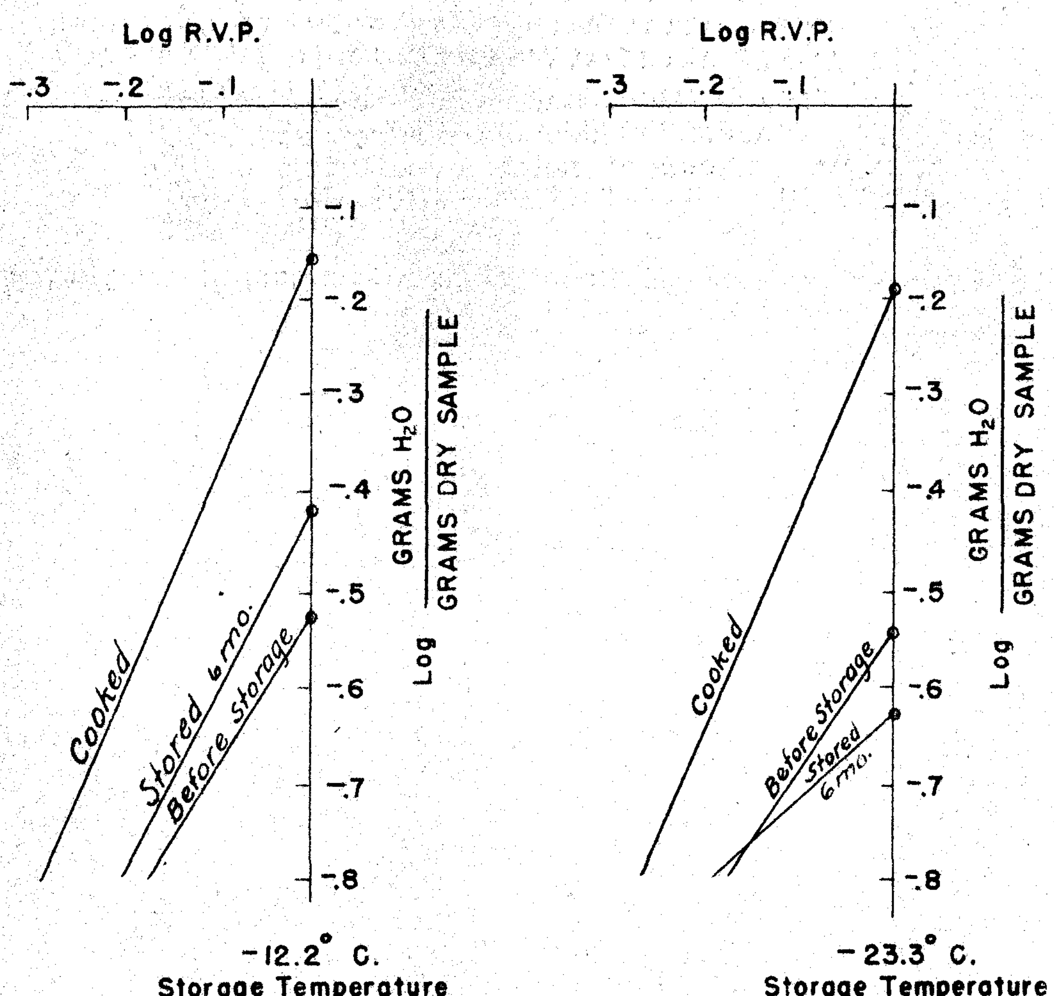


Fig. 11. Covariance analysis of data for R. V. P. isotherms. These data were obtained from the B series of roasters stored 6 months at -12.2°C. (10°F.) and -23.3°C. (-10°F.). The data include the logarithmic regression lines resulting from vapor pressure analyses of breast muscle samples removed before freezing, after 6 months' frozen storage, and after cooking. As the y-intercept approaches the origin, more waterbinding becomes evident.

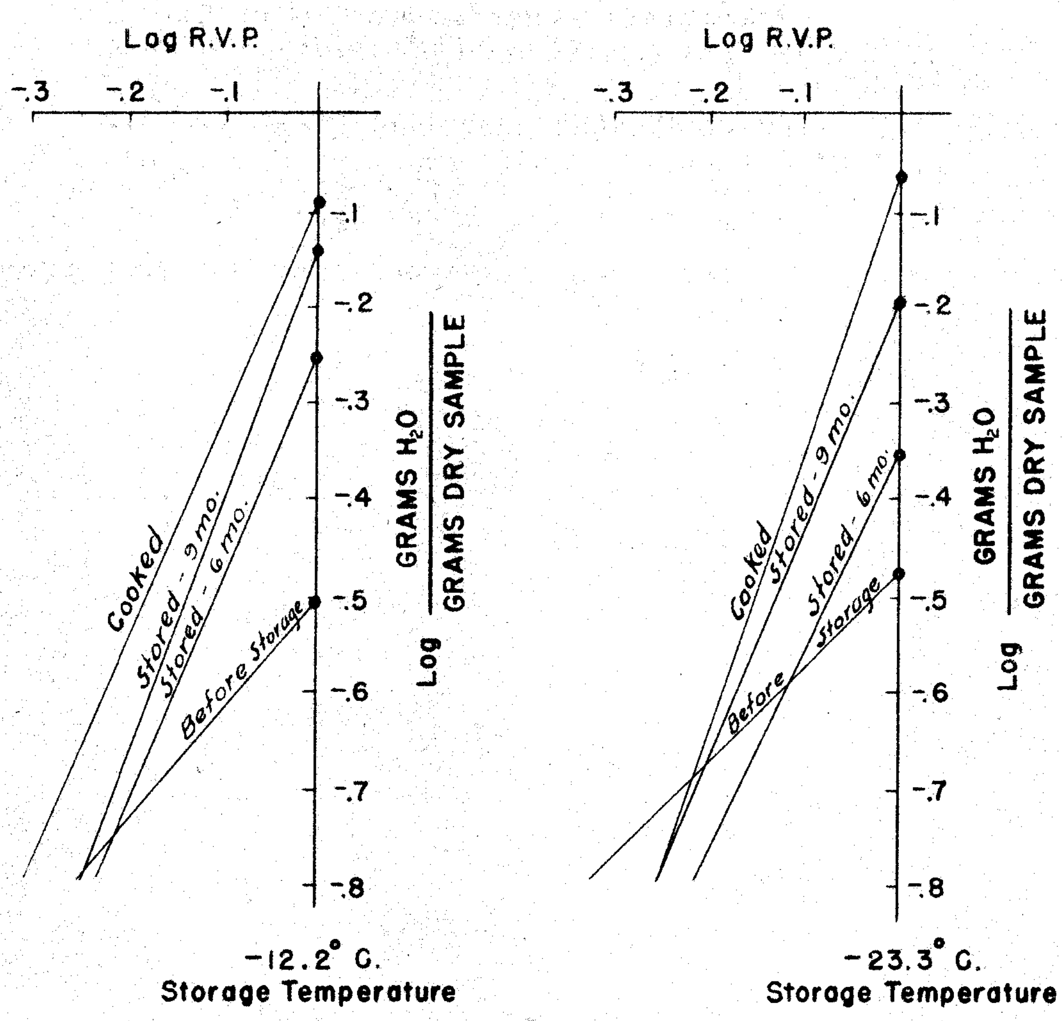


Fig. 12. Covariance analysis of data for R. V. P. isotherms. These data were obtained from the C series of roasters stored 9 months at -12.2°C. (10°F.) and -23.3°C. (-10°F.). The data include the logarithmic regression lines resulting from vapor pressure analyses of breast muscle samples removed before freezing, after 6 months' frozen storage, after 9 months' frozen storage, and after cooking. As the y-intercept approaches the origin, more waterbinding is evident.

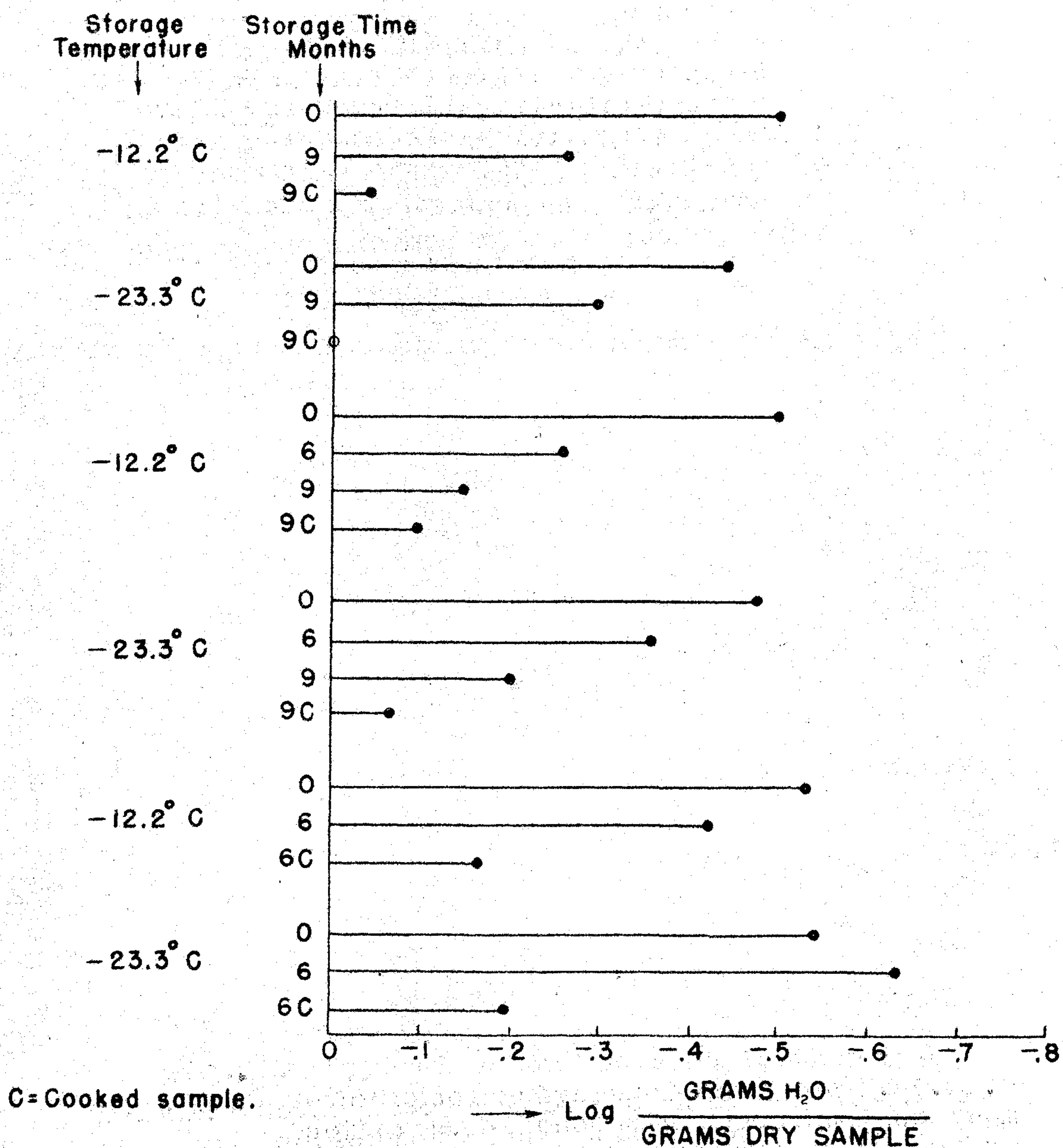


Fig. 13. Summary of covariance analysis of R. V. P. tests for all the roasters held in frozen storage. The length of each line indicates the distance from the origin for the y-intercept of the logarithmic regression line. The shorter lines represent the greater degree of waterbinding for the samples and series indicated.

Per Cent Moisture Loss

Average moisture percentages for groups of 10 roasters are shown in table I. The overall average water content before storage for breast muscle of male roasters was 74.4 per cent. Moisture lost in storage was almost negligible. The exact per cent water content and per cent water lost during frozen storage for all roasters is given in the appendix (tables 21-26). The average moisture lost because of cooking of the roasters stored 9 months was 4.1 per cent. The average moisture lost because of cooking of the roasters stored 6 months was also 4.1 per cent.

Juiciness Scores

The average juiciness scores for each group of 10 roasters in the three series, A, B, and C, are shown below, and an indication of the storage temperature and the storage time is included. It will be recalled that the score for juiciness was from 0 to 10, 10 being the highest score.

		Average juiciness score
Series A -	9 months at -12.2°C. (10°F.)	6.3
	9 months at -23.3°C. (-10°F.)	6.8
Series B -	6 months at -12.2°C.	7.0
	6 months at -23.3°C.	7.0
Series C -	9 months at -12.2°C.	6.6
	9 months at -23.3°C.	6.8

The juiciness scores for individual birds appear in table 27 in the appendix.

Table I

The per cent water in roaster breast muscle before frozen storage, after frozen storage, and in the cooked sample for different storage times and different storage temperatures.

Group of 10 birds Storage time	 Storage temp.	Water before storage	Water 6 months' storage	Water storage loss	Water 9 months' storage	Water storage loss	Water cooked sample	Water cooking loss
mo.	°F.	%	%	%	%	%	%	%
9	10	74.0	--	--	73.9	-0.1	68.5	-5.4
9	-10	73.6	--	--	73.4	-0.2	68.9	-4.5
6 - 9	10	74.4	73.5	-0.9	73.5	-0.0	70.5	-3.0
6 - 9	-10	74.0	73.1	-0.9	73.8	-0.3	70.4	-3.4
6	10	75.0	74.7	-0.3	--	--	70.8	-3.9
6	-10	74.8	74.7	-0.1	--	--	70.4	-4.3
	Ave.	74.4		-0.6				

The vapor pressure determinations for per cent water content in 30 cooked samples stored at -12.2°C. (10°F.) are plotted as a function of juiciness in figure 14. Similarly the data for the 30 cooked samples stored at -23.3°C. (-10°F.) are shown in figure 15. From statistical analysis the correlation between the two tests on the same birds, *i.e.*, the per cent water in the cooked samples (vapor pressure method), and the juiciness is represented by *r*. The equation for the regression line is given and the regression line is drawn in.

From the study of a scattergraph no correlation was evident between vapor pressure determinations of water in cooked samples and press fluid percentages. The data for press fluid are shown in table 27 in the appendix.

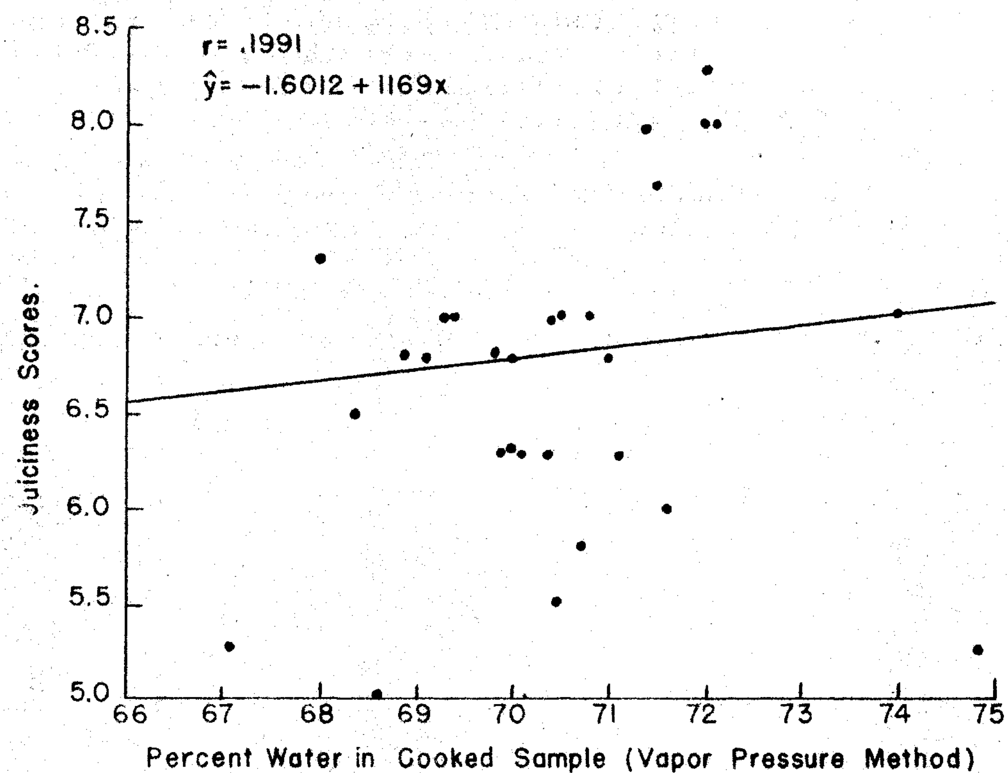


Fig. 14. Regression of juiciness scores on vapor pressure analyses for per cent moisture in samples of cooked roaster breast muscle. Data from the 30 roasters stored at -12.2°C. (10°F.).

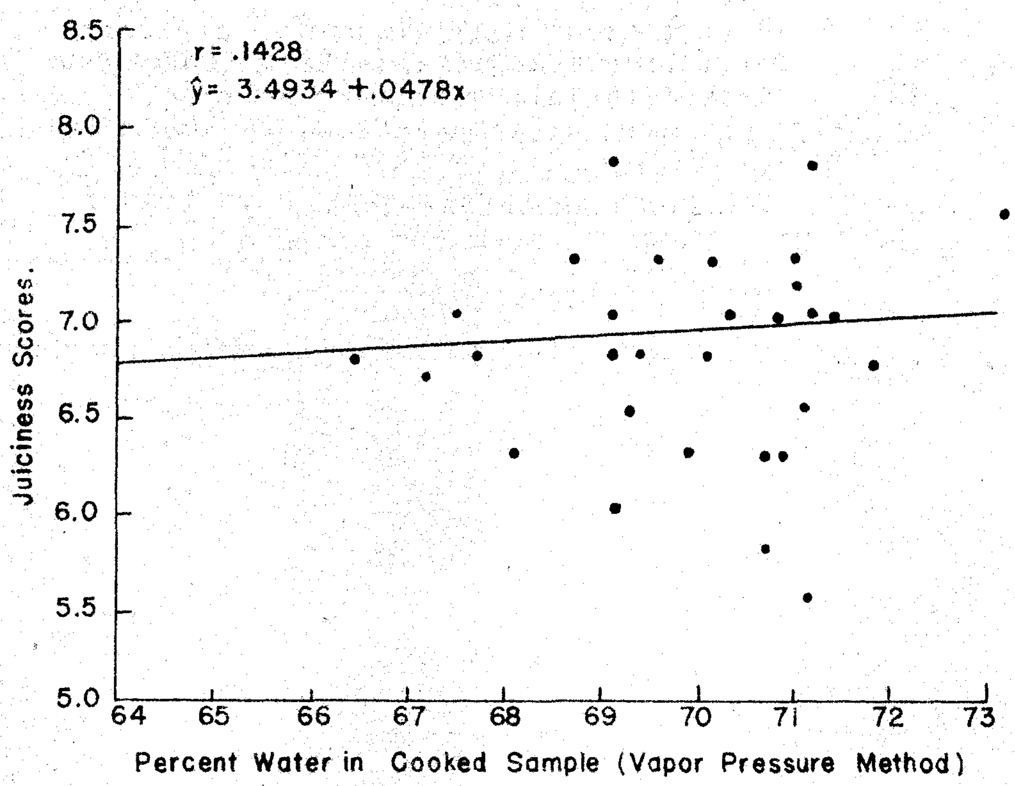


Fig. 15. Regression of juiciness scores on vapor pressure analyses for per cent moisture in samples of cooked roaster breast muscle. Data from the 30 roasters stored at -23.3°C. (-10°F.).

DISCUSSION

The Interpretation of the Data in Relation to the Quantity of Bound Water in the Sample

Water present in the sample as shown by weight, but not exerting vapor pressure, was considered to be bound water. The less vapor pressure that the water in a sample was able to exert at a certain moisture level the more bound water it was considered to contain. The moisture level was always on the basis of grams of water per gram of dry sample. If the original vapor pressure reading was lowered because of the presence of bound water, the consequent R. V. P. would be lowered in like manner.

A study of the upper portion (nearest 1.0 R. V. P.) of the vapor pressure isotherms of figure 7 (series A, stored 9 months at -12.2°C.) revealed that this portion of the curve was near 1.0 R. V. P. before storage, nearer 0.9 R. V. P. after storage, and nearest 0.8 R. V. P. after cooking. Because of the shift of this part of the curve from an R. V. P. of 1.0 downward, the samples stored 9 months were considered to contain more bound water per unit gram of dry roaster sample. The cooked samples were considered to contain more bound water per unit gram of dry roaster sample than the samples stored 9 months.

The same set of data as shown in figure 7 is shown as part of figure 9 (-12.2°C.). The y-intercept of the regression line before storage is actually -0.505. For the samples tested after storage it is -0.260. The cooked samples indicated an intercept of -0.040. The nearer this intercept approached the origin, the greater the amount of bound water considered present in a gram of dry sample.

The Quantity of Bound Water in Relation to Storage Time and Cooking

Before storage, the roaster breast muscle samples in this experiment contained the least bound water. One exception to this was noted in the case of the B series (figure 11, -23.3°C.), in which the birds had been stored 6 months. No explanation is offered for this variation from the general trend.

The general trend, with the aforementioned exception, was that stored breast muscle indicated more waterbinding. The roasters stored 9 months showed more waterbinding than those stored 6 months. This was apparent from a study of the y-intercepts of figures 10, 11, and 12.

The cooked breast muscle always had the greatest amount of bound water per gram dry sample. This is again shown in figures 10, 11, and 12. Roasters cooked after 6 months' storage had less bound water than those cooked after 9 months' storage.

A summary of the relation of storage time to waterbinding is shown graphically in figure 13.

The Quantity of Bound Water in Relation to Temperature of Frozen Storage

In all series of roasters, those stored at the lower temperature, -23.3°C. (-10°F.), showed less water binding in the raw stored breast muscle than those stored at -12.2°C. (10°F.). This is evident from a study of the data shown in figures 10, 11, and 12. A shift from bound to free water seemed to take place in the raw breast muscle of the birds stored 6 months at -23.3°C.

In the cooked samples, changes in waterbinding caused by differences in storage temperature (-12.2°C. and -23.3°C.) are not evident. In fact, the quantity of bound water in cooked breast muscle stored at the two different temperatures appears to be approximately the same when the same length of storage time is considered.

Moisture Lost During Frozen Storage

The vapor pressure method of analysis for per cent water content in raw unstored samples of breast muscle of male roasters proved fairly consistent. The average total water content was found to be 74.4 per cent. This compared favorably with the 74.6 per cent water content found by Harshaw (22).

During frozen storage the water loss was less than 1 per cent in all cases. The A series roasters, stored 9 months at -12.2°C. (10°F.), lost only 0.1 per cent moisture from the breast muscle. Wrapping of the birds in cellophane no doubt prevented noticeable desiccation.

No obvious correlation between per cent free water loss and time of frozen storage or temperature of frozen storage is apparent.

Moisture Lost During Cooking

The actual amount of water lost by the breast muscle during cooking averaged 4.1 per cent for birds stored 9 months and also for birds stored 6 months. There was no apparent correlation of cooking loss with length of frozen storage time and storage temperature. The cooking loss as estimated in the manner described in this work pertained to free water lost in cooking and did not include such losses as liquid fat and volatile materials.

Juiciness Scores

The extremely low correlations (0.199 and 0.143) between per cent water in the cooked samples and juiciness scores may indicate that the juiciness factor of palatability involves more than the free water content of the breast muscle. Part of the juicy sensation that the judge experiences may be caused by other factors, one of which may be the quantity of liquid fat in the sample.

The question arises regarding the relation of juiciness scores to bound water in the samples. A study of the y-intercepts (appendix table 28) and juiciness scores (appendix table 27) reveals markedly less waterbinding in the roasters stored 6 months. The average juiciness scores were slightly more for these birds than for those stored the longer period of time.

Individual Sample Variations in R. V. P. Analysis

Between the duplicate samples of the same roaster there was often wide variation in the R. V. P. readings at the same moisture levels. This occurred more frequently in the cooked samples. Incomplete equilibration may sometimes have been part of the cause. A change from bound to free water and *vice versa* may have caused variation in sample readings. This latter could also be a reason for variation between roasters. Changing chemical and physical conditions of the samples would affect the vapor pressure readings.

Between chickens biological differences could cause some variation.

Denaturation of Protein

According to the results in this study, the nearer the y-intercept approaches the origin in figures 10, 11, and 12 the greater the amount of bound water in the breast muscle. The most highly denatured muscles involved were those that were cooked. Since the y-intercepts of the cooked muscle samples were near the origin, the cooked muscle apparently contained the most bound water. The uncooked muscle after storage probably was denatured to some extent. The graphic data, figures 10, 11, and 12, show that in most instances this muscle contains more bound water than the raw unstored muscle. Time of storage, storage temperature, the presence of salts, and the very process of dehydration may have been interacting factors in causing denaturation of uncooked samples. The added effect of cooking would, of course, increase the degree of denaturation.

Muscle Protein Structure and Waterbinding

Neurath *et al.* (39) suggest that muscle protein may change from a fibrous to a more nearly spherical configuration upon denaturation. If this more spherical configuration includes a rolling up of the polypeptide chain, then more water might be expected to be taken up by salt linkages and by hydrogen bonding.

As dehydration progresses, the salts in the muscle juices become more concentrated. The presence of salt has been shown to depress the hydration of some proteins.

The pH value of muscle is not constant after the death of the animal and during storage. Increase of lactic acid after death causes a lowered pH, and this lactic acid increase is variable from animal to animal. After the minimum pH has been reached with further changes in the muscle, the pH increases. According to Finn (16) dehydration and frozen storage could effect a change in pH. A shift in pH to either side of the iso-electric point might cause waterbinding.

As water freezes out of the muscle in the frozen storage process, the remaining unfrozen solution must have a greater salt concentration. This changing salt concentration could also affect the process of waterbinding.

Effect of Room Temperature upon Vapor Pressure Readings

The vapor pressure readings of water at 27.5°C. (81.5°F.) were affected by the temperature of the room. The correction for day-to-day variation of room temperature was taken into account by actually measuring the vapor pressure of some distilled water held in the constant temperature bath at 27.5°C. This vapor pressure variation is shown in figure 4. According to Edser (15) the vapor pressure reading obtained might be that of the vapor found in the coldest part of the vapor pressure apparatus. This would explain the lowered vapor pressure of water when the room temperature was below the temperature of the bath (27.5°C.). However, it does not explain the continued rise in the vapor pressure of water when the room was above the temperature of the bath. It is suggested that some heat conductivity might have occurred along the walls of the desiccating tubes, which in turn may have affected the temperature of the water being vaporized.

Vapor Pressure Equilibration

In general, the time of equilibration (4 minutes) seemed ample throughout the experiment for the uncooked samples. The cooked samples which had been stored 9 months were more frequently not at equilibrium at the end of 4 minutes. It usually took 8 minutes to establish a fair degree of equilibrium, and occasionally the time was 12 minutes. The vapor pressure reading established after the longer period of time was seldom more than 2 millimeters higher than at 4 minutes' equilibration. Usually it was less. This fact, of course, would tend to make the amount of bound water appearing in the cooked samples seem somewhat higher than it actually was. However, in the experiment it was considered best to continue with the same equilibration time (4 minutes) for all samples, both raw and cooked.

It seemed that no matter how long the equilibration period, there was always some tendency for vapor pressure readings of the cooked samples to fluctuate. This was seldom the case with the uncooked samples. Probably chemical changes and physical changes induced by the cooking caused part of this fluctuation.

The establishment of completely satisfactory vapor pressure equilibrium should be considered in further work on this problem. The circumstances of this experiment indicate a trend in results which could be considered fairly reliable. For more accurate measurements of bound water in quantitative amounts the problem of equilibration should be further studied. It might be suggested that particle surface area also be considered. In addition, more accurate vapor pressure readings could be made if a liquid of lower specific gravity than mercury were used in the manometer of the vapor pressure apparatus.

The Adsorption of Water Vapor by Proteins

The adsorption of water by proteins has been discussed by Bull (12). He theorizes that protein molecules in the solid state are linked to form coherent planes, the exposed surfaces of which are hydrophilic. Bull also adds that water is adsorbed between these planes. Pauling (40) has said that the amino acid residues of proteins provide much of the attraction for the adsorbed water molecules. Pauling used the data of Bull (12) and Shaw (45) and found that the initial adsorption of a single molecule of water per polar side chain occurred with some proteins, and that interesting deviations from this simple relation also could take place.

Possibly more study should be made on the desorption process of chicken breast muscle, including the nature and extent of the surfaces involved.

CONCLUSIONS

Much more might be done on waterbinding in relation to palatability of frozen stored poultry. This study has been exploratory, and the work needs the verification of other investigators. Under the conditions that have been described, the following conclusions may be drawn:

1. The quantity of bound water in roaster breast muscle had a tendency to increase during frozen storage. At the end of 9 months' frozen storage there was more bound water than at the end of 6 months.

2. There was slightly more waterbinding in breast muscle stored at the higher storage temperature, -12.2°C. (10°F.), than there was in that held at the lower storage temperature, -23.3°C. (-10°F.).

3. The quantity of bound water in the breast muscle was noticeably increased by cooking.

4. Neither the quantity of bound water nor the per cent of total water in cooked breast muscle seemed to correlate with juiciness scores.

SUMMARY

The purpose of this problem was to explore the nature of water content changes of poultry held in frozen storage and to study the relationship of these changes to juiciness scores.

Vapor pressure analyses for bound water and total water content were made on the pectoralis major breast muscles of 60 roasters. These analyses were made first on the fresh raw muscle, later after frozen storage, and finally after cooking.

The roasters were divided for frozen storage into series A, B, and C, each series containing 20 birds. Each series was then subdivided into two groups, one group of 10 birds being stored at -12.2°C. (10°F.) and the other 10 stored at -23.3°C. (-10°F.). Series A was stored for 9 months, series B for 6 months, and series C for 9 months. However, series C differed from series A in that samples for vapor pressure analyses were removed from the roasters at the end of 6 months' storage as well as at the end of the 9 months' period.

The vapor pressure method of analysis successfully indicated waterbinding in chicken breast muscle during storage and also further waterbinding as a result of cooking. The longer storage time (9 months) and the higher storage temperature (-12.2°C.) apparently caused the greater degree of waterbinding.

The average water content of all of the fresh samples was 74.4 per cent. The free water lost because of storage was slight, but that lost because of cooking was 4.1 per cent.

No correlation was found between juiciness and either bound water or total water in the breast muscle of the roasters.

LITERATURE CITED

1. Astbury, W. T. The hydrogen bond in protein structure. Trans. Farad. Soc. 36:871-880. 1940.

2. Baker, L. C. The constituents of meat acting as pointers of change. J. Soc. Chem. Ind. 54:154T-157T. 1935.

3. Barnicoat, C. R. Store-burn in frozen meat products. N. Z. J. Science and Tech. 15:248-254. 1934.

4. Beach, E. F., Monks, B. and Robinson, A. The amino acid composition of animal tissue proteins. J. Biol. Chem. 148:431-439. 1943.

5. Birdseye, C. Some scientific aspects of quick-freezing perishable flesh products. II. Packaging of flesh products for quick freezing. Ind. Eng. Chem., Ind. ed. 21:573-576. 1929.

6. Blanchard, K. C. Water free and bound. Cold Spring Harbor Symposia Quant. Biol. 8:1-8. 1940.

7. Brady, D. E., Frei, P. and Hickman, C. W. Effect of freezing rate on quality of broiled steaks. Food Res. 7:388-393. 1942.

8. Briggs, D. R. Water relationships in colloids. I. Vapor pressure measurements on elastic gels. J. Phys. Chem. 35:2914-2929. 1931.

9. -------- Water relationships in colloids. II. "Bound" water in colloids. J. Phys. Chem. 36:367-386. 1932.

10. Brunauer, S., Emmett, P. H. and Teller, E. Adsorption of gases in multimolecular layers. J. Am. Chem. Soc. 60:309-319. 1938.

11. Bull, Henry B. Physical biochemistry. 1st ed. New York, John Wiley and Son, Inc. 1943.

12. -------- Adsorption of water vapor by proteins. J. Am. Chem. Soc. 66:1499-1507. 1944.

13. Chick, H. and Martin, C. J. On heat denaturation of proteins. J. Physiol. 40:404-430. 1910.

14. Cook, W. H. Frozen storage of poultry. II. Bloom. Food Res. 4:419-424. 1939.

15. Edser, E. Heat for advanced students. 2d ed. p. 224. London, Macmillan and Co., Ltd. 1929.

16. Finn, D. B. Denaturation of proteins in muscle juice by freezing. Proc. Roy. Soc. (London) B, 111:396-410. 1932.

17. Freundlich, H. Colloid and capillary chemistry. (English translation) 2d ed. p. 111. New York, E. P. Dutton and Co. 1922.

18. Gortner, R. A. Outlines of biochemistry. 2d ed. p. 278. New York, John Wiley and Son, Inc. 1938.

19. -------- and Gortner, W. A. The cryoscopic method for the determination of "bound water." J. Gen. Physiol. 17:327-339. 1934.

20. -------- and Jones, Ivan D. Free and bound water in elastic and non-elastic gels. J. Phys. Chem. 36:387-434. 1932.

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

22. Harshaw, H. M. Physical and chemical composition of chickens and turkeys. Tabs. U. S. Egg and Poultry Mag. 48:365-366. 1942.

23. Hill, A. V. The state of water in muscle and blood and the osmotic behavior of muscle. Proc. Roy. Soc. (London) B, 106:477-505. 1930.

24. Hiner, R. L., Madsen, L. L. and Hankins, O. G. Histological characteristics of tenderness and drip losses of beef in relation to temperature of freezing. Food Res. 10:312-324. 1945.

25. Kaupp, B. F. The anatomy of the domestic fowl. p. 24. Philadelphia, W. B. Saunders Co. 1918.

26. Kistler, S. S. The measurement of "bound" water by the freezing method. J. Am. Chem. Soc. 58:901-907. 1936.

27. Langmuir, I. The adsorption of gases on plane surfaces of glass, mica and platinum. J. Am. Chem. Soc. 40:1361-1403. 1918.

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

29. Lloyd, D. J. Protein structure and water absorption. 42:1-10. 1938.

30. --------- Imbibition of proteins by water. Cereal Chem. 15:25-33. 1938.

31. ---------, Marriott, R. H. and Pleass, W. B. The swelling of protein fibers. I. The swelling of collagen. Trans. Farad. Soc. 29:554-563. 1933.

32. --------- and Phillips, H. Protein structure and protein hydration. Trans. Farad. Soc. 29:132-146. 1933.

33. --------- and Pleass, W. B. The absorption of water by gelatin. Biochem. J. 21:1352-1366. 1927.

34. Makower, B. and Dehority, G. L. Equilibrium moisture content of dehydrated vegetables. Ind. Eng. Chem., Ind. ed. 35:193-197. 1943.

35. --------- and Myers, S. A new method for the determination of moisture in dehydrated vegetables. Proc. Inst. Food Tech. 1943:156-164. 1943.

36. Moran, T. Post mortem and refrigeration changes in meat. J. Soc. Chem. Ind. 54:149T-151T. 1935.

37. Mirsky, A. E. The coagulation of myosin in muscle. J. Gen. Physiol. 20:461-474. 1936-1937.

38. Muralt, A. L. von and Edsall, J. T. Studies in the physical chemistry of muscle globulin. III. The anisotropy of myosin and the angle of isocline. J. Biol. Chem. 89:315-351. 1930.

39. Neurath, H., Greenstein, J. P., Putnam, F. W. and Erickson, J. O. The chemistry of protein denaturation. Chem. Rev. 34:156-265. 1944.

40. Pauling, L. The adsorption of water by proteins. J. Am. Chem. Soc. 67:555-557. 1945.

41. Pennington, M. E. Changes taking place in chickens during cold storage. U. S. Dept. of Agr. Yearbook 1907:197-206. 1907.

42. Pickett, G. Modification of the Brunauer-Emmett-Teller theory of multimolecular adsorption. J. Am. Chem. Soc. 67:1958-1962. 1945.

43. Rubner, M. Über die Wasserbindung in Kolloiden mit besonderer Berücksichtigung des quergestreiften Muskels. Abh. Preuss. Akad. Wiss., Phys.-Math. Klasse. 1922:1-70. 1922.

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

45. Shaw, T. M. The surface area of crystalline egg albumin. J. Chem. Phys. 12:391-392. 1944.

46. Smith, E. C. B. Section I. Meat: Physiology of rigor mortis. Great Britain, Dept. Sci. Ind. Res., Report of the Food Investigation Board. 1938:15-19. 1939.

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

48. -------- The proteins of meat. J. Soc. Chem. Ind. 54: 152T-154T. 1935.

49. -------- A scheme for the approximate determination of the proteins of muscle. J. Soc. Chem. Ind. 53: 351T-354T. 1934.

50. -------- Native and denatured muscle proteins. Proc. Roy. Soc. (London) B, 124:136-150. 1937-1938.

51. Snedecor, G. W. Statistical methods. 4th ed. p. 318. Ames, Ia., Collegiate Press. 1946.

52. Stewart, G. F. Poultry products research: guide for research workers, including a list of some problems in project form. Ia. Agr. Exp. Sta. Res. Bul. 299:766-767. 1942.

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

54. Szent-Gygorgyi, A. Contraction and the chemical structure of the muscle fibril. J. of Colloid Sci. 1:1-19. 1946.

55. Theones, F. Untersuchungen zur Frage der Wasserverbindung in Kolloiden und tierischen Geweben. Biochem. Z. 157:174-186. 1925.

56. Tressler, D. K. Freezer burn on refrigerated poultry. Inst. Am. Poultry Industries. Chicago. Library Service No. 12. Sept. 1935.

57. -------- Freezer burn on refrigerated poultry. U. S. Egg and Poultry Mag. 41:33-46. 1935.

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

ACKNOWLEDGMENTS

The author wishes to express her sincere appreciation to Miss Belle Lowe for both suggesting and helping plan this study and for the thought and kindly assistance given in preparing the manuscript. The writer also wishes to express her deep appreciation to Dr. Louise Peet for the many ways in which she has helped and for the opportunity of research study. To Dr. George Stewart gratitude is expressed for technical advice and for making the study of this problem possible. To Mr. George W. Snedecor and to Mrs. Bernice Brown the author expresses her gratitude for their interest, advice and help in the statistical analysis of the data. The writer appreciates the cheerful cooperation rendered by Miss Rena Wills and Miss Belle Lowe in cooking the roasters and also she is grateful for the handling of the palatability scoring by Miss Wills.

The author appreciates the contribution rendered by Mr. Harry Slosberg in killing and dressing the roasters used for this study. The kindness of Dr. C. H. Werkman and Mr. M. M. Jones in helping obtain the dry ice used in this experiment was much appreciated.

APPENDIX

Table 1

R. V. P.: The number of roaster, the number of sample, the moisture content (grams H_2O/grams dry sample), and the relative vapor pressure of samples from the breast muscle BEFORE FREEZING for roasters of series A, frozen and stored 9 months at -12.2°C. (10°F.).

Roaster no.	Sample no.	Grams H_2O / Grams dry sample	Relative Vapor Pressure (R. V. P.)
151	1	.397	1.00
		.089	.80
	2	.400	.95
		.087	.85
155	1	.250	.99
		.071	.48
	2	.464	1.00
		.090	.52
158	1	.397	.95
		.102	.61
	2	.276	.87
		.096	.43
162	1	.445	.93
		.099	.35
	2	.745	.97
		.274	.85
166	1	.685	.94
		.196	.80
	2	.870	.96
		.194	.80
192	1	.995	1.00
		.133	.69
	2	1.130	1.00
		.324	.83
196	1	.619	1.00
		.120	.50
	2	--	--
		--	--
200	1	1.170	1.00
		.301	.79
	2	1.415	1.00
		.104	.53
204	1	--	--
		--	--
	2	--	--
		--	--
208	1	.742	1.00
		.085	.58
	2	.800	1.00
		.085	.63

Table 2

R. V. P.: The number of roaster, the number of sample, the moisture content (grams H_2O/grams dry sample), and relative vapor pressure of samples from the breast muscle AFTER 9 MONTHS' FROZEN STORAGE for roasters of series A, frozen and stored 9 months at -12.2°C. (10°F.).

Roaster no.	Sample no.	Grams H_2O / Grams dry sample	Relative Vapor Pressure (R. V. P.)
151	1	.261	.81
		.093	.47
	2	.145	.81
		.064	.28
155	1	.282	.81
		.096	.44
	2	.308	.81
		.089	.44
158	1	.466	.93
		.116	.59
	2	.653	.97
		.164	.65
162	1	.578	.89
		.214	.66
	2	.560	.93
		.148	.55
166	1	.705	.89
		.150	.68
	2	.592	.86
		.105	.67
192	1	.256	.77
		.079	.37
	2	.309	.89
		.091	.53
196	1	.380	.85
		.095	.33
	2	.314	.88
		.077	.37
200	1	.412	.89
		.158	.65
	2	.339	.89
		.092	.45
204	1	.430	.89
		.112	.46
	2	.490	.78
		.482	.70
208	1	.539	.79
		.195	.61
	2	--	--
		--	--

Table 3

R. V. P.: The number of roaster, the number of sample, the moisture content (grams H_2O/grams dry sample), and relative vapor pressure of samples from the breast muscle AFTER COOKING for roasters of series A, frozen and stored 9 months at -12.2°C. (10°F.).

Roaster no.	Sample no.	Grams H_2O / Grams dry sample	Relative Vapor Pressure (R. V. P.)
151	1	.695	.92
		.222	.62
	2	.518	.85
		.144	.55
155	1	.915	.85
		.372	.74
	2	.990	.81
		.374	.77
158	1	.803	.78
		.368	.64
	2	1.000	.75
		.415	.71
162	1	.730	.93
		.342	.86
	2	.905	.82
		.455	.75
166	1	.480	.85
		.164	.55
	2	.655	.93
		.242	.70
192	1	.495	.77
		.191	.53
	2	.438	.80
		.145	.53
196	1	.371	.75
		.133	.49
	2	.520	.71
		.173	.67
200	1	.367	.80
		.139	.43
	2	.389	.76
		.141	.43
204	1	.468	.79
		.164	.55
	2	.479	.76
		.166	.58
208	1	.705	.91
		.268	.74
	2	.356	.74
		.127	.56

Table 4

R. V. P.: The number of roaster, the number of sample, the moisture content (grams H_2O/grams dry sample), and relative vapor pressure of samples from the breast muscle BEFORE FREEZING for roasters of series A, frozen and stored 9 months at -23.3°C. (-10°F.).

Roaster no.	Sample no.	Grams H_2O / Grams dry sample	Relative Vapor Pressure (R. V. P.)
150	1	.233	.93
		.042	.19
	2	.362	.96
		.089	.65
154	1	.485	.98
		.120	.61
	2	.816	1.00
		.211	.80
159	1	.208	.82
		.066	.35
	2	.423	.95
		.083	.46
163	1	.481	.96
		.115	.55
	2	.747	.96
		.124	.51
167	1	.282	.96
		.061	.26
	2	.456	.96
		.109	.62
193	1	1.05	1.00
		.216	.71
	2	1.15	1.00
		.322	.82
197	1	.897	1.00
		.175	.88
	2	.690	1.00
		.130	.42
201	1	1.015	--
		.144	.55
	2	1.21	--
		.238	.59
205	1	--	--
		--	--
	2	--	--
		--	--
209	1	.905	1.00
		.090	.71
	2	--	--
		--	--

Table 5

R. V. P.: The number of roaster, the number of sample, the moisture content (grams H_2O/grams dry sample), and relative vapor pressure of samples from the breast muscle AFTER 9 MONTHS' FROZEN STORAGE for roasters of series A, frozen and stored 9 months at -23.3°C. (-10°F.).

Roaster no.	Sample no.	Grams H_2O / Grams dry sample	Relative Vapor Pressure (R. V. P.)
150	1	.231	.66
		.107	.40
	2	.158	.66
		.074	.21
154	1	.408	.81
		.110	.55
	2	.344	.77
		.855	.40
159	1	.367	.85
		.092	.43
	2	.429	.96
		.091	.47
163	1	.427	.89
		.131	.55
	2	.535	.96
		.132	.59
167	1	.972	.93
		.179	.78
	2	.407	.89
		.065	.35
193	1	.360	.88
		.078	.41
	2	.248	.84
		.065	.73
197	1	.376	.85
		.112	.57
	2	.323	.92
		.073	.33
201	1	.430	.89
		.148	.57
	2	.335	.81
		.095	.45
205	1	.462	.79
		.165	.63
	2	.497	.78
		.156	.60
209	1	.199	.72
		.078	.37
	2	.331	.78
		.152	.51

Table 6

R. V. P.: The number of roaster, the number of sample, the moisture content (grams H_2O/grams dry sample), and relative vapor pressure of samples from the breast muscle AFTER COOKING for roasters of series A, frozen and stored 9 months at -23.3°C. (-10°F.).

Roaster no.	Sample no.	Grams H_2O / Grams dry sample	Relative Vapor Pressure (R. V. P.)
150	1	.685	.66
		.188	.59
	2	.987	.89
		.348	.70
154	1	1.03	.81
		.451	.74
	2	.835	.89
		.329	.70
159	1	.725	.82
		.246	.64
	2	.880	.71
		.314	.67
163	1	.693	.82
		.260	.71
	2	.870	.78
		.346	.75
167	1	.720	.85
		.316	.81
	2	.925	.89
		.438	.74
193	1	.243	.73
		.089	.29
	2	.542	.84
		.199	.69
197	1	.471	.75
		.149	.60
	2	.665	.71
		.285	.68
201	1	.248	.79
		.097	.43
	2	.402	.80
		.142	.59
205	1	.438	.72
		.133	.65
	2	.645	.86
		.316	.65
209	1	.546	.74
		.270	.63
	2	.738	.74
		.354	.63

Table 7

R. V. P.: The number of roaster, the number of sample, the moisture content (grams H_2O/grams dry sample), and relative vapor pressure of samples from the breast muscle BEFORE FREEZING for roasters of series B, frozen and stored 6 months at -12.2°C. (10°F.).

Roaster no.	Sample no.	Grams H_2O / Grams dry sample	Relative Vapor Pressure (R. V. P.)
152	1	.221	.97
		.055	.37
	2	.514	.97
		.072	.48
156	1	.218	.85
		.056	.62
	2	.660	--
		.148	.59
160	1	.226	1.00
		.060	.32
	2	.350	1.00
		.096	.47
164	1	.277	.87
		.070	.34
	2	.384	1.00
		.056	.32
168	1	.558	1.00
		.151	.55
	2	.625	1.00
		.079	.47
170	1	.970	.97
		.248	.61
	2	.493	.91
		.113	.61
174	1	1.51	1.00
		.228	.64
	2	1.32	1.00
		.440	.71
178	1	.705	1.00
		.146	.58
	2	1.025	1.00
		.285	.68
182	1	.435	.93
		.078	.37
	2	.793	.96
		.112	.41
186	1	1.01	.99
		.147	.50
	2	1.12	1.00
		.188	.63

Table 8

R. V. P.: The number of roaster, the number of sample, the moisture content (grams H_2O/grams dry sample), and relative vapor pressure of samples from the breast muscle AFTER 6 MONTHS' STORAGE for roasters of series B, frozen and stored 6 months at -12.2°C. (10°F.).

Roaster no.	Sample no.	Grams H_2O / Grams dry sample	Relative Vapor Pressure (R. V. P.)
152	1	.558	1.00
		.152	.76
	2	.715	1.00
		.176	.84
156	1	.693	1.00
		.111	.52
	2	.460	1.00
		.067	.28
160	1	.483	.96
		.128	.58
	2	.545	.96
		.115	.46
164	1	.470	1.00
		.157	.31
	2	.159	.73
		.060	.65
168	1	.647	.93
		.189	.70
	2	.470	.93
		.190	.62
170	1	.177	.70
		.062	.31
	2	.140	.70
		.051	.23
174	1	.222	.85
		.084	.43
	2	.383	.88
		.130	.61
178	1	.177	.77
		.068	.33
	2	.263	.81
		.084	.41
182	1	.220	1.00
		.065	.30
	2	.123	.73
		.051	.18
186	1	.273	.73
		.108	.41
	2	.135	.61
		.054	.18

Table 9

R. V. P.: The number of roaster, the number of sample, the moisture content (grams H_2O/grams dry sample), and relative vapor pressure of samples from the breast muscle AFTER COOKING for roasters of series B, frozen and stored 6 months at -12.2°C. (10°F.).

Roaster no.	Sample no.	Grams H_2O / Grams dry sample	Relative Vapor Pressure (R. V. P.)
152	1	.532	1.00
		.192	.60
	2	.525	1.00
		.218	.78
156	1	.567	.89
		.253	.66
	2	.590	.89
		.250	.73
160	1	.535	.93
		.247	.69
	2	.535	.98
		.270	.77
164	1	.960	.93
		.430	.73
	2	.802	.77
		.320	.73
168	1	.523	.76
		.234	.68
	2	.575	.76
		.263	.66
170	1	.740	.86
		.390	.75
	2	.713	.82
		.348	.71
174	1	.593	1.00
		.245	.74
	2	.433	.89
		.160	.66
178	1	.545	.85
		.199	.49
	2	.467	.89
		.196	.49
182	1	.283	.92
		.053	.35
	2	.639	.88
		.249	.65
186	1	.660	.96
		.300	.76
	2	.595	.96
		.214	.67

Table 10

R. V. P.: The number of roaster, the number of sample, the moisture content (grams H_2O/grams dry sample), and relative vapor pressure of samples from the breast muscle BEFORE FREEZING for roasters of series B, frozen and stored 6 months at -23.3°C. (-10°F.).

Roaster no.	Sample no.	Grams H_2O / Grams dry sample	Relative Vapor Pressure (R. V. P.)
153	1	.317	1.00
		.077	.59
	2	.642	1.00
		.285	.95
157	1	.240	.78
		.063	.25
	2	.450	1.00
		.110	.51
161	1	.391	1.00
		.053	.28
	2	.--	--
		--	--
165	1	.256	.81
		.066	.44
	2	.387	1.00
		.093	.55
169	1	.613	.96
		.135	.59
	2	.287	.91
		.038	.36
171	1	.388	.91
		.092	.42
	2	.617	.98
		.115	.56
175	1	.852	.93
		.324	.71
	2	1.35	1.00
		.094	.35
179	1	.995	1.00
		.280	.61
	2	1.00	1.00
		.153	.61
183	1	.685	.97
		.147	.48
	2	.998	.97
		.161	.52
187	1	.913	1.00
		.204	.50
	2	.775	1.00
		.126	.50

Table 11

R. V. P.: The number of roaster, the number of sample, the moisture content (grams H_2O/grams dry sample), and relative vapor pressure of samples from the breast muscle AFTER 6 MONTHS' STORAGE for roasters of series B, frozen and stored 6 months at -23.3°C. (-10°F.).

Roaster no.	Sample no.	Grams H_2O / Grams dry sample	Relative Vapor Pressure (R. V. P.)
153	1	1.05	1.00
		.250	.92
	2	.735	1.00
		.139	.56
157	1	.324	1.00
		.072	.40
	2	.570	1.00
		.108	.52
161	1	.270	.97
		.054	.31
	2	.240	.97
		.057	.27
165	1	.407	1.00
		.128	.54
	2	.300	1.00
		.158	.50
169	1	.536	.93
		.149	.54
	2	.310	.81
		.085	.35
171	1	.234	.96
		.082	.38
	2	.220	.75
		--	--
175	1	.268	.88
		.080	.45
	2	.374	.96
		.107	.53
179	1	.320	.96
		.098	.53
	2	.310	.95
		.128	.53
183	1	.144	.81
		.024	.26
	2	.243	.80
		.083	.45
187	1	.224	.73
		.067	.33
	2	.131	.80
		.051	.33

Table 12

R. V. P.: The number of roaster, the number of sample, the moisture content (grams H_2O/grams dry sample), and relative vapor pressure of samples from the breast muscle AFTER COOKING for roasters of series B, frozen and stored 6 months at -23.3°C. (-10°F.).

Roaster no.	Sample no.	Grams H_2O / Grams dry sample	Relative Vapor Pressure (R. V. P.)
153	1	.610	1.00
		.270	.68
	2	.560	1.00
		.264	.68
157	1	.655	.96
		.230	.66
	2	.486	.73
		.189	.66
161	1	.560	.98
		.176	.77
	2	.655	.93
		.330	.77
165	1	.750	.77
		.270	.66
	2	.860	.85
		.340	.85
169	1	.625	.76
		.302	.72
	2	.637	.84
		.323	.80
171	1	.553	.88
		.209	.75
	2	.582	.82
		.250	.71
175	1	.296	.74
		.113	.47
	2	.403	.89
		.153	.55
179	1	.382	.81
		.156	.57
	2	.414	.89
		.170	.49
183	1	.617	.92
		.272	.72
	2	.735	.96
		.279	.92
187	1	.502	.84
		.166	.72
	2	.384	.92
		.125	.59

Table 13

R. V. P.: The number of roaster, the number of sample, the moisture content (grams H_2O/grams dry sample), and relative vapor pressure of samples from the breast muscle BEFORE FREEZING for roasters of series C, frozen and stored 9 months at -12.2°C. (10°F.), but a sample removed at end of 6 months' storage for an R. V. P. test.

Roaster no.	Sample no.	Grams H_2O / Grams dry sample	Relative Vapor Pressure (R. V. P.)
172	1	1.14	1.00
		.348	.74
	2	1.35	1.00
		.186	.62
176	1	1.17	.97
		.241	.64
	2	1.63	.97
		.310	.67
180	1	.630	1.00
		.127	.48
	2	.825	1.00
		.149	.54
184	1	1.44	1.00
		.342	.55
	2	1.325	.95
		.107	.42
188	1	.913	1.00
		.227	.68
	2	.677	1.00
		.104	.43
190	1	1.14	1.00
		.273	.68
	2	1.32	1.00
		.200	.80
194	1	1.09	1.00
		.164	.91
	2	1.23	1.00
		.105	.54
198	1	1.18	1.00
		.138	.59
	2	1.15	1.00
		.317	.88
202	1	.456	1.00
		.083	.60
	2	--	--
		--	--
206	1	1.17	1.00
		.139	.46
	2	1.03	1.00
		.088	.58

Table 14

R. V. P.: The number of roaster, the number of sample, the moisture content (grams H_2O/grams dry sample), and relative vapor pressure of samples from the breast muscle AFTER 6 MONTHS' FROZEN STORAGE for roasters of series C, frozen and stored 9 months at -12.2°C. (10°F.).

Roaster no.	Sample no.	Grams H_2O / Grams dry sample	Relative Vapor Pressure (R. V. P.)
172	1	.627	.92
		.209	.69
	2	.330	.81
		.104	.53
176	1	.410	.82
		.115	.49
	2	.690	.77
		.062	.18
180	1	.293	.96
		.087	.42
	2	.354	.78
		.105	.46
184	1	.437	.92
		.145	.63
	2	.165	.72
		.058	.23
188	1	.378	.84
		.071	.45
	2	.154	.69
		.060	.26
190	1	.448	.93
		.123	.56
	2	.525	.93
		.160	.64
194	1	.440	.93
		.130	.60
	2	.352	.75
		.090	.42
198	1	.407	.89
		.145	.60
	2	.364	.86
		.098	.56
202	1	.535	.84
		.301	.73
	2	.318	.89
		.103	.57
206	1	.525	.92
		.192	.66
	2	.507	.94
		.184	.66

Table 15

R. V. P.: The number of roaster, the number of sample, the moisture content (grams H_2O/grams dry sample), and relative vapor pressure of samples from the breast muscle AFTER 9 MONTHS' FROZEN STORAGE for roasters of series C, frozen and stored 9 months at -12.2°C. (10°F.), but a sample was removed at the end of 6 months' storage for an R. V. P. test.

Roaster no.	Sample no.	Grams H_2O / Grams dry sample	Relative Vapor Pressure (R. V. P.)
172	1	.378	.93
		.080	.46
	2	.411	.93
		.083	.46
176	1	.542	.89
		.126	.57
	2	.750	.86
		.272	.64
180	1	.475	.93
		.129	.56
	2	.470	.93
		.104	.53
184	1	.546	.82
		.198	.56
	2	.635	.96
		.154	.64
188	1	.954	.96
		.578	.76
	2	.450	.84
		.166	.53
190	1	.854	.92
		.327	.76
	2	.936	.96
		.378	.84
194	1	.274	.70
		.071	.43
	2	.174	.66
		.059	.25
198	1	.388	.79
		.115	.49
	2	.382	.75
		.129	.49
202	1	.728	.92
		.297	.81
	2	.515	.85
		.138	.64
206	1	.388	.76
		.150	.51
	2	.355	.90
		.084	.69

Table 16

R. V. P.: The number of roaster, the number of sample, the moisture content (grams H_2O/grams dry sample), and relative vapor pressure of samples from the breast muscle AFTER COOKING for roasters of series C, frozen and stored 9 months at -12.2°C. (10°F.), but a sample was removed at the end of 6 months' storage for an R. V. P. test.

Roaster no.	Sample no.	Grams H_2O / Grams dry sample	Relative Vapor Pressure (R. V. P.)
172	1	.705	1.00
		.282	.65
	2	.925	.92
		.409	.76
176	1	.963	.87
		.434	.76
	2	.870	.91
		.326	.69
180	1	.396	.83
		.145	.48
	2	.660	.79
		.237	.58
184	1	.556	1.00
		.218	.61
	2	.512	.85
		.191	.77
188	1	.479	.75
		.195	.46
	2	.682	.72
		.287	.48
190	1	.496	.82
		.158	.40
	2	.727	.70
		.229	.78
194	1	.232	.73
		.074	.25
	2	.525	.77
		.193	.63
198	1	.423	.69
		.065	.51
	2	--	--
		--	--
202	1	.584	.81
		.233	.61
	2	.610	.74
		.230	.61
206	1	.420	.60
		.191	.49
	2	.407	.70
		.151	.42

Table 17

R. V. P.: The number of roaster, the number of sample, the moisture content (grams H_2O/grams dry sample), and relative vapor pressure of samples from the breast muscle BEFORE FREEZING for roasters of series C, frozen and stored 9 months at -23.3°C. (-10°F.), but a sample was removed at the end of 6 months' storage for an R. V. P. test.

Roaster no.	Sample no.	Grams H_2O / Grams dry sample	Relative Vapor Pressure (R. V. P.)
173	1	.795	.97
		.137	.51
	2	1.05	1.00
		.124	.58
177	1	1.20	1.00
		.205	.57
	2	1.50	.97
		.169	.57
181	1	.725	1.00
		.190	.61
	2	.880	1.00
		.146	.50
185	1	1.36	.95
		.237	.55
	2	1.60	.93
		.228	.69
189	1	.653	1.00
		.147	.56
	2	1.105	1.00
		.188	.52
191	1	1.05	1.00
		.170	.68
	2	.985	1.00
		.156	.72
195	1	1.14	1.00
		.193	.69
	2	1.14	1.00
		.146	.67
199	1	.995	1.00
		.173	.67
	2	1.32	1.00
		.315	.75
203	1	1.17	.96
		.092	.51
	2	.713	1.00
		.096	.49
207	1	1.36	1.00
		.140	.71
	2	.890	1.00
		.209	.88

Table 18

R. V. P.: The number of roaster, the number of sample, the moisture content (grams H_2O/grams dry sample), and relative vapor pressure of samples from the breast muscle AFTER 6 MONTHS' FROZEN STORAGE for roasters of series C, frozen and stored 9 months at -23.3°C. (-10°F.).

Roaster no.	Sample no.	Grams H_2O / Grams dry sample	Relative Vapor Pressure (R. V. P.)
173	1	.441	.80
		.164	.61
	2	.417	.80
		.124	.57
177	1	.283	.78
		.099	.42
	2	.217	.82
		.125	.38
181	1	.447	.96
		.157	.63
	2	.274	.79
		.069	.29
185	1	.447	.84
		.179	.67
	2	.325	.81
		.080	.43
189	1	.310	.88
		.085	.37
	2	.224	.73
		--	--
191	1	.273	.86
		.053	.38
	2	.278	.97
		.068	.42
195	1	.353	.82
		.095	.49
	2	.285	.89
		.472	.35
199	1	.174	.85
		.051	.41
	2	.264	.73
		.082	.49
203	1	.772	.96
		.380	.85
	2	.308	.93
		.083	.47
207	1	.266	.85
		.073	.40
	2	.320	.85
		.080	.40

Table 19

R. V. P.: The number of roaster, the number of sample, the moisture content (grams H_2O/grams dry sample), and relative vapor pressure of samples from the breast muscle AFTER 9 MONTHS' FROZEN STORAGE for roasters of series C, frozen and stored 9 months at -23.3°C. (-10°F.), but a sample was removed at the end of 6 months' storage for an R. V. P. test.

Roaster no.	Sample no.	Grams H_2O / Grams dry sample	Relative Vapor Pressure (R. V. P.)
173	1	.460	.89
		.105	.38
	2	.470	.89
		.082	.49
177	1	.712	.97
		.202	.71
	2	.590	.89
		.194	.67
181	1	.380	.86
		.144	.56
	2	.440	.89
		.108	.49
185	1	.560	.93
		.195	.64
	2	.517	.89
		.184	.56
189	1	.630	.92
		.254	.77
	2	.556	.88
		.218	.69
191	1	.950	.96
		.380	.82
	2	.813	.92
		.204	.80
195	1	.214	.70
		.085	.32
	2	.169	.74
		.062	.25
199	1	.400	.75
		.126	.49
	2	.455	.75
		.144	.57
203	1	.292	.77
		.097	.47
	2	.301	.94
		.079	.43
207	1	.324	.76
		.148	.44
	2	.410	.79
		.109	.37

Table 20

R. V. P.: The number of roaster, the number of sample, the moisture content (grams H_2O/grams dry sample), and relative vapor pressure of samples from the breast muscle AFTER COOKING for roasters of series C, frozen and stored 9 months at -23.3°C. (-10°F.), but a sample was removed at the end of 6 months' storage for an R. V. P. test.

Roaster no.	Sample no.	Grams H_2O / Grams dry sample	Relative Vapor Pressure (R. V. P.)
173	1	.600	1.00
		.185	.69
	2	.613	.88
		.180	.61
177	1	.682	.80
		.257	.69
	2	.747	1.00
		.293	.68
181	1	.284	.86
		.098	.30
	2	.458	.83
		.140	.48
185	1	.675	.80
		.280	.69
	2	.564	.80
		.208	.65
189	1	.486	.65
		.176	.55
	2	.465	.72
		.177	.55
191	1	.611	.85
		.178	.62
	2	.600	.78
		.185	.66
195	1	.420	.80
		.147	.61
	2	.500	.69
		.131	.53
199	1	.535	.81
		.185	.66
	2	.542	.82
		.176	.62
203	1	.479	.78
		.151	.59
	2	.311	.78
		.098	.48
207	1	.535	.70
		.175	.63
	2	.363	.73
		.098	.49

Table 21

Moisture Content: The number of the roaster, the sample number, the per cent water content before storage, the per cent water after 9 months' frozen storage, the per cent water content after cooking of roasters in series A, stored 9 months at -12.2°C. (10°F.).

Roaster no.	Sample no.	% H_2O* before storage	% H_2O* after 9 months' storage	% H_2O* after cooking
151	1	74.1	73.5	70.7
	2	72.8	73.9	71.5
155	1	74.1	73.6	70.2
	2	74.8	73.6	70.8
158	1	74.5	74.1	70.0
	2	74.6	74.1	69.8
162	1	75.7	74.3	68.0
	2	75.4	74.6	68.0
166	1	74.1	74.0	69.8
	2	74.4	73.8	69.7
192	1	73.9	74.1	68.9
	2	74.0	73.8	70.0
196	1	73.1	73.0	67.3
	2	--	73.0	66.8
200	1	76.1	75.0	70.8
	2	76.0	75.0	70.0
204	1	71.4	73.8	70.4
	2	71.0	73.6	69.8
208	1	72.9	73.6	69.1
	2	73.2	--	69.1
Means		74.0	73.9	68.5

$$\text{*Per cent water} = \frac{\text{Grams } H_2O}{\text{Total sample weight (grams)}} \times 100.$$

Table 22

Moisture Content: The number of the roaster, the sample number, the per cent water content before storage, the per cent water content after 9 months' frozen storage, the per cent water content after cooking of roasters in series A, stored 9 months at -23.3°C. (-10°F.).

Roaster no.	Sample no.	% H_2O* before storage	% H_2O* after 9 months' storage	% H_2O* after cooking
150	1	74.1	73.5	71.4
	2	73.5	73.6	70.8
154	1	74.7	74.7	71.3
	2	74.4	74.0	72.3
159	1	74.4	74.6	70.5
	2	74.3	73.7	70.0
163	1	72.4	73.6	69.4
	2	73.3	72.6	68.8
167	1	74.7	74.7	68.4
	2	74.1	74.6	67.8
193	1	74.0	73.5	67.0
	2	74.0	74.4	65.8
197	1	73.1	72.5	68.3
	2	73.4	73.2	67.2
201	1	73.7	73.6	69.3
	2	73.7	72.8	69.3
205	1	70.7	73.2	68.2
	2	75.0	70.4	66.8
209	1	72.5	72.5	68.5
	2	72.2	72.4	67.6
Means		73.6	73.4	68.9

*Per cent water = $\frac{\text{Grams } H_2O}{\text{Total sample weight (grams)}} \times 100.$

Table 23

Moisture Content: The number of the roaster, the sample number, the per cent water content before storage, the per cent water content after 6 months' frozen storage, the per cent water content after cooking of roasters in series B, stored 6 months at -12.2°C. (10°F.).

Roaster no.	Sample no.	% H_2O* before storage	% H_2O* after 6 months' storage	% H_2O* after cooking
152	1	74.6	73.4	71.7
	2	74.4	73.6	72.3
156	1	74.5	74.8	70.5
	2	74.7	74.6	70.2
160	1	74.0	74.0	71.0
	2	74.0	72.2	71.7
164	1	74.9	74.9	68.4
	2	74.5	75.0	68.8
168	1	75.5	74.8	70.0
	2	74.4	74.5	71.6
170	1	74.7	74.6	68.8
	2	75.3	75.1	69.3
174	1	74.7	75.3	71.6
	2	74.5	74.7	70.6
178	1	75.3	75.6	72.0
	2	75.1	75.0	71.9
182	1	75.3	75.4	71.7
	2	75.7	75.5	71.4
186	1	77.1	75.6	72.0
	2	77.4	75.4	71.0
Means		75.0	74.7	70.8

$$\text{*Per cent water} = \frac{\text{Grams } H_2O}{\text{Total sample weight (grams)}} \times 100.$$

Table 24

Moisture Content: The number of the roaster, the sample number, the per cent water content before storage, the per cent water content after 6 months' frozen storage, the per cent water content after cooking of roasters in series B, stored 6 months at -23.3°C. (-10°F.).

Roaster no.	Sample no.	% H_2O* before storage	% H_2O* after 6 months' storage	% H_2O* after cooking
153	1	73.4	74.0	72.2
	2	73.6	74.2	71.5
157	1	74.7	73.6	68.8
	2	74.4	73.9	69.3
161	1	74.5	75.1	70.6
	2	--	75.6	71.8
165	1	74.4	74.9	70.2
	2	74.4	75.0	64.1
169	1	76.9	75.4	69.8
	2	73.7	75.0	70.3
171	1	75.2	76.2	71.9
	2	75.8	75.5	73.0
175	1	74.7	74.4	70.6
	2	74.8	74.1	71.1
179	1	75.2	73.9	71.3
	2	75.2	73.6	70.7
183	1	75.6	75.0	70.9
	2	75.8	75.7	71.2
187	1	74.6	74.8	69.3
	2	75.3	74.6	69.9
Means		74.8	74.7	70.4

*Per cent water $= \frac{\text{Grams } H_2O}{\text{Total sample weight (grams)}} \times 100.$

Table 25

Moisture Content: The number of the roaster, the sample number, the per cent water content before storage, the per cent water content after 6 months' frozen storage, the per cent water content after 9 months' frozen storage, the per cent water content after cooking, of roasters in series C, stored 9 months at -12.2°C. (10°F.), with a sample removed for a moisture test after 6 months' frozen storage.

Roaster no.	Sample no.	% H_2O* before storage	% H_2O* after 6 months' storage	% H_2O* after 9 months' storage	% H_2O* after cooking
172	1	75.9	74.2	74.3	71.9
	2	76.3	73.6	73.4	72.5
176	1	74.6	75.4	75.5	69.3
	2	74.9	75.2	76.0	70.8
180	1	73.5	74.2	73.0	70.2
	2	73.6	74.6	73.2	71.8
184	1	75.2	74.4	75.2	75.2
	2	75.0	74.6	74.5	74.5
188	1	75.1	74.3	74.8	69.3
	2	74.4	74.7	74.6	68.5
190	1	73.9	72.9	73.5	70.8
	2	73.8	72.7	74.0	69.2
194	1	74.2	72.2	72.8	70.0
	2	74.6	72.6	74.0	68.5
198	1	73.5	71.9	72.0	70.5
	2	73.4	72.1	72.5	--
202	1	73.6	72.7	71.3	68.7
	2	--	71.4	67.2	68.0
206	1	74.2	73.6	74.2	70.6
	2	74.3	73.0	74.9	70.8
Means		74.4	73.5	73.5	70.5

*Per cent water = $\frac{\text{Grams } H_2O}{\text{Total sample weight (grams)}}$ x 100.

Table 26

Moisture Content: The number of the roaster, the sample number, the per cent water content before storage, the per cent water content after 6 months' frozen storage, the per cent water content after 9 months' frozen storage, the per cent water content after cooking, of roasters in series C, stored 9 months at -23.3°C. (-10°F.), with a sample removed for a moisture test after 6 months' frozen storage.

Roaster no.	Sample no.	% H_2O* before storage	% H_2O* after 6 months' storage	% H_2O* after 9 months' storage	% H_2O* after cooking
173	1	74.3	66.5	73.7	69.0
	2	71.2	73.4	73.5	69.7
177	1	74.9	74.2	74.6	71.1
	2	74.2	74.6	73.7	68.6
181	1	74.8	75.3	74.2	70.8
	2	75.0	74.6	74.1	70.6
185	1	74.9	74.7	74.2	73.0
	2	75.0	74.8	75.0	73.4
189	1	75.0	75.0	73.8	71.0
	2	74.3	75.1	74.3	71.4
191	1	73.2	72.6	--	69.7
	2	73.7	73.6	74.5	70.4
195	1	73.5	71.3	73.7	68.3
	2	72.0	72.6	74.2	69.1
199	1	74.3	71.7	73.5	68.8
	2	73.9	73.0	73.0	69.4
203	1	73.7	72.6	72.7	71.3
	2	73.8	71.3	72.2	70.2
207	1	74.5	73.0	73.2	70.6
	2	74.1	73.0	74.3	70.8
Means		74.0	73.1	73.8	70.4

*Per cent water = $\frac{\text{Grams } H_2O}{\text{Total sample weight (grams)}} \times 100.$

Table 27

Palatability Scores and Press Fluid: The number of roaster, the temperature of storage, the length of time in frozen storage, the per cent of press fluid, and the palatability scores for juiciness on 60 roasters held in frozen storage at -12.2°C. (10°F.) and at -23.3°C. (-10°F.) for periods of 6 and 9 months, that is, series A, B, and C. Half the birds for each series were stored at -12.2°C., the other half at -23.3°C.

A series - 20 roasters stored 9 months. R.V.P. tests made before storage, after frozen storage, and on cooked samples.

B series - 20 roasters stored 6 months. R.V.P. tests made before storage, after frozen storage, and on cooked samples.

C series - 20 roasters stored 9 months. R.V.P. tests made before storage, after 6 months' frozen storage, after 9 months' frozen storage, and on cooked samples.

Series and roaster no.	Storage temp.	Frozen storage time	Press fluid	Average juiciness scores (Possible score = 10)
	°C.	mo.	%	
A series				
151	-12.2	9	50.4	6.3
155			50.9	5.5
158			49.3	6.3
162			49.7	7.3
166			45.1	6.8
192			52.3	7.0
196			48.8	5.3
200			51.0	6.3
204			51.1	5.0
208			49.4	6.8
150	-23.3	9	47.7	5.8
154			53.4	7.0
159			48.4	7.0
163			48.2	7.8
167			49.3	7.0
193			44.9	6.8
197			49.8	6.8
201			46.0	6.5
205			48.3	7.0
209			48.7	6.3

(continued)

Table 27 (continued)

Series and roaster no.	Storage temp.	Frozen storage time	Press fluid	Average juiciness scores (Possible score = 10)
	°C.	mo.	%	
B series				
152	-12.2	6	52.0	8.0
156			47.2	7.0
160			57.4	8.0
164			48.8	5.0
168			55.6	7.0
170			47.3	6.8
174			50.5	6.3
178			46.9	8.3
182			51.1	6.0
186			48.8	7.7
153	-23.3	6	54.5	7.0
157			44.7	6.8
161			47.8	7.8
165			54.6	6.7
169			52.9	6.8
171			51.9	7.0
175			49.3	6.3
179			53.7	7.3
183			50.0	6.5
187			49.6	7.3
C series				
172	-12.2	9	49.5	8.0
176			50.2	6.3
180			52.2	6.8
184			55.0	5.3
188			48.4	6.8
190			49.6	6.3
194			51.6	7.0
198			47.7	7.0
202			44.6	6.5
206			50.6	5.8
173	-23.3	9	49.7	6.8
177			45.0	6.3
181			49.2	5.8
185			55.6	7.8
189			52.4	7.0
191			51.4	7.3
195			54.9	7.3
199			50.5	6.0
203			48.9	7.0
207			50.9	6.3

Table 28

Covariance Analysis Summary: Data from 60 roasters kept in frozen storage at -12.2°C. (10°F.) and -23.3°C. (-10°F.) for periods of 6 and 9 months. Table shows the series, the temperature of storage, the storage time, the abscissa and ordinate of the calculated mean, the slope of the regression line, and the resultant intercept on the y-axis. Explanation of series A, B, and C appears with table 27. (C after time of storage indicates a cooked sample.)

Series	Storage temp. °C.	Frozen storage time mo.	Mean point x	Mean point y	Slope (b)	y-intercept x = 0
A	-12.2	0	.157	.797	1.9016	-.505
		9	.149	.609	2.3735	-.260
		9 C	.155	.452	2.6346	-.040
A	-23.3	0	.137	.680	1.8515	-.440
		9	.156	.642	2.2932	-.295
		9 C	.143	.424	2.9417	-.000
B	-12.2	0	.217	.860	1.597	-.526
		6	.168	.742	1.889	-.416
		6 C	.118	.426	2.168	-.160
B	-23.3	0	.233	.910	1.644	-.541
		6	.161	.708	.995	-.627
		6 C	.122	.474	2.404	-.189
C	-12.2	0	.218	.762	1.204	-.503
		6	.154	.629	2.441	-.256
		9	.149	.550	2.741	-.145
		9 C	.171	.461	2.233	-.095
C	-23.3	0	.213	.680	.9569	-.478
		6	.152	.669	2.1755	-.355
		9	.144	.552	2.4781	-.200
		9 C	.168	.541	3.0160	-.060

Algebraic symbols:

x = log R. V. P.

y = log (grams H_2O/grams dry sample)

b = slope of regression line