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The effect of several variables on the texture of freeze-dried formulated strawberry slices

James Franklin Amos

To the Graduate Council:

I am submitting herewith a thesis written by James Franklin Amos entitled "The effect of several variables on the texture of freeze-dried formulated strawberry slices." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Food Science and Technology.

Melvin R. Johnston, Major Professor

We have read this thesis and recommend its acceptance:

James L. Collins, Robert Shrode

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

December 4, 1967

To the Graduate Council:

I am submitting herewith a thesis written by James Franklin Amos entitled "The Effect of Several Variables on the Texture of Freeze-Dried Formulated Strawberry Slices." I recommend that it be accepted for nine quarter hours of credit in partial fulfillment of the requirements for the degree of Master of Science, with a major in Food Technology.

Melvin K. Johnson
Major Professor

We have read this thesis and recommend its acceptance:

Robert R. Brooke

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THE EFFECT OF SEVERAL VARIABLES ON THE TEXTURE OF FREEZE-DRIED FORMULATED STRAWBERRY SLICES

A Thesis

Presented to

the Graduate Council of

The University of Tennessee

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

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by

James Franklin Amos

December 1967

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CHAPTER I

INTRODUCTION

Freeze-dried slices of natural strawberries are rather fragile and susceptible to disintegration during packaging and handling while in the dry state. In addition they rapidly lose their integrity and become very flaccid during the process of rehydration. Little work has been done on these two aspects of the freeze-drying of the strawberry.

Wegener et al. (213)* used low methoxyl pectin, a kelp extractive, and an Irish moss extractive with frozen strawberries. Murphy et al. (137) studied the effect of low methoxyl pectin on the texture of frozen strawberries. Hanson et al. (67) investigated the effect of additives such as pectin, gelatin, gums, and Irish moss extractives on texture stability during the frozen storage of foods. Lloyd (107) received a patent for improving frozen food texture by the use of starch conversion syrup solids. Swenson and Miers (131,188) worked with the effect of low methoxyl pectin, calcium chloride, and sucrose on fruit texture. Collins and Wiley (31) used calcium salts to increase apple slice firmness by interaction with inherent pectic substances. In most cases the texture of the fruit being studied was improved by the use of such additives.

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*The numbers in parentheses represent similarly numbered references in the Literature Cited.

Several workers have investigated the relationship of sweeteners to the texture of frozen products. Some of these workers are Dawson et al. (41), Talburt et al. (198), Sistrunk et al. (176), Joslyn (85), Bartlett and Hard (15), and Bockian and Aref (20). In general it could be said that monosaccharides and disaccharides usually harmed texture and higher molecular weight carbohydrate polymers improved texture.

This study was undertaken to determine the feasibility of improving the dry texture (resistance to shattering) and the rehydrated texture (resistance to loss of integrity when placed in water) of freeze-dried strawberry slices. The process led to a sliced, freeze-dried, formulated strawberry product incorporating a sweetener and a colloidal stabilizer. The variables which were tested are as follows:

1. Effect of amount and type of sugar
2. Effect of method of blending
3. Effect of method of freezing.
4. Effect of amount of water
5. Effect of kind and level of colloidal stabilizer
6. Effect of deaeration immediately following the blending process.
7. Effect of temperature of the water used in blending.

CHAPTER II

REVIEW OF LITERATURE

I. FREEZE-DRYING PROCESS

The freeze-drying process consists of removing moisture from a product in the frozen state by sublimation. The low temperatures used in the process inhibit undesirable chemical and biochemical reactions and minimize the loss of volatile aromatic compounds. The dried product is light in weight, can be stored in air-tight containers for long periods, and has good color, flavor, and nutritive value. Where low temperature facilities are absent, freeze-dried foods would be more desirable than frozen or dehydrated foods (111).

Freeze-drying differed from ambient temperature and pressure drying in several respects. Freeze-drying permitted the use of thicker pieces because of superior reconstitution; air drying gave a closure of texture due to capillary forces inherent in the process. The Maillard browning reaction proceeded to a much greater extent in the case of air drying. Faster drying rates could be attained with freeze-drying because of the larger surface areas involved. Freeze-drying of foods was first investigated during the late 1930's in the United States and in Great Britain. It was used during World War II to provide quality dehydrated foods against which other dehydrated foods could be judged. The revival of interest in food freeze-drying in the late 1930's was due largely to the development of the accelerated

freeze-drying process. True freeze-drying was said to occur only when the material was held below its eutectic temperature. It was said to be hard to pass heat into drying tissue while water vapor was being removed. The process could be improved by scraping off the surface layer as it became dry.. The vacuum used was in the range of one mm. of mercury or less. The problems of maintaining such a vacuum were said to become acute in large scale operations (80).

According to Flosdorf (57) freeze-drying was a laboratory-scale method until World War II, when the needs for blood serum, plasma, food, vitamins, and antibiotics expanded it to a large-scale operation. According to Fisher (56), the demands imposed by modern warfare, together with the recognition of deficiencies in existing military rations, have combined to provide the impetus for the development of food freeze-drying.

Freeze-drying developments in the United States have been due mainly to the efforts of the Army Quartermaster Food and Container Institute, the Stokes Company (manufacturers of freeze-drying equipment), the Lipton Company, the Campbell Soup Company, the United Fruit Company (processors of freeze-dried shrimp), and the Armour Company (manufacturers of freeze-dried camping meals) (80).

In addition to the advantages of freeze-drying of foods mentioned by Luh (111), Ryan (160) listed several other advantages of freeze-drying as compared with other industrial drying processes. These were as follows: (1) the stopping of bacterial and enzymatic

action; (2) the retention of the original configuration of molecular constituents; and (3) the lack of change in volume.

Several different methods and types of equipment have been used for freeze-drying. Using a general theory developed for the design of freeze-drying equipment, it was possible to compute drying rates for different materials in different apparatus and to design an apparatus suitable for the required purpose. For the drying of animal tissues where the area involved was small, the requirements of the apparatus were not critical. The same theory indicated that the drying of plant tissues and other biologicals required equipment whose design was more critical (181).

A survey indicated that mechanisms for facilitating heat transfer were as follows: expanded metal meshes to promote conduction and to expedite vapor removal, dielectric heating units, and a radiant energy source aided by black trays for increased absorption of heat. Vapor removal devices included steam ejectors, refrigerated vapor trays, mechanical pumps, and absorption systems utilizing chemicals. Various types of vapor releases, from spiked plates to grid type heaters with channels or exits into heating plates could be used. One idea for an ideal freeze-drying process was a vacuum tunnel long enough to dry the product in one pass. The apparatus would utilize air locks at each end, roller equipped trays, and a low pressure carrier system that introduced heated inert gas into the drying chamber (149).

A freeze-drying apparatus thought to minimize the cost and complexity of the apparatus and the time required for drying was described by Glick and Malmstrom (60). The apparatus used a vacuum pump with a larger than usual capacity in order to make slight leaks unimportant and to shorten the time required to reach high vacuum, a reduced distance between the tissue sample and the water vapor trap to increase the rate of dehydration, a reduced water vapor tension in the trap to make dehydration more complete, and an apparatus with a large bore and a minimum of joints and angles in order to speed evacuation.

A major disadvantage of freeze-drying was the cost of the process. Some current research was aimed at finding heating systems and operating cycles which would give a cheaper process (12).

Two types of equipment were used: the steam ejector and the refrigerated condenser. The steam ejector had a low initial cost and a high operating cost, while the refrigerated condenser had a high initial cost and a low operating cost (12). A freeze-drying assembly described by Annear (5) used a mechanical refrigeration coil.

A freeze-drying vessel used by Friend and Payne (59) employed two stainless steel beakers mounted one inside the other with vacuum stopcocks in the outer beaker. A coolant was used in the beakers to freeze the material in a centrifuge bottle. The bottles were then connected to the stopcocks for drying.

Vartapetyan (207) described a rapid freeze-drying apparatus consisting of a flask for the material which was to be dried and a

condenser which was immersed in a cooling mixture after a pressure of about 0.1 mm. of mercury had been established. Continuous evacuation of the apparatus was not necessary.

An apparatus described by Williams (216) was said to be capable of extremely rapid freeze-drying. The technique involved impinging micro-droplets of a suspension at high velocity on a colloidon-coated surface kept at -75 to -170° C. The frozen droplets were then sublimed at -50° C. in a high vacuum apparatus. It was estimated that the small droplets passed through their freezing point in 10^{-5} sec.

Several methods of freeze-drying involved the use of a vacuum coupled with a dehydrating agent. If a long enough time period could be allowed for freeze-drying, a mechanical pump plus a vapor trap filled with a mixture of solid carbon dioxide (dry ice) and acetone or ethanol would be adequate. Where time was an important factor, a design employing a gas trap containing a copper Dewar reservoir could be used (61). Vapor traps employing dry ice or calcium carbide were described by Meredith (128) and by Holden (76,77). Taylor (201) received a patent for an apparatus which used a high vacuum pump connected to a manifold containing phosphorus pentoxide as a desiccating agent. Stowell (185) described an apparatus using liquid nitrogen as a moisture trap. Hickman (74) patented a process which involved subjecting frozen material to a pressure of less than 3 mm. and then removing the evolved water vapor with an immiscible liquid.

Freeze-drying by immersion in a dehydrating agent has been used. The method of Blank (19) dissolved ice from the frozen tissue and cells

by immersion in chemical dehydrating agents which were liquid at low temperatures. Examples were glycols, acetone, and alcohols. Wistreich and Blake (221) freeze-dried pieces of frozen comminuted meat by boiling in toluene under reduced pressure. The dehydration was performed at 30° C. and took place without melting the ice. The dried product showed all the characteristics of freeze-dried defatted meat. Propane and propylene were used in a similar manner by Hjeln and Moller (75).

According to Kramer and Hill (97), a simple freeze-drying apparatus requiring neither elaborate pumping equipment nor vapor traps could be produced by using a stream of dry gas to carry away water molecules. Treffenberg (203) dried objects at -30° C. and 5 to 10 mm. of mercury by a stream of dry air or nitrogen which had previously been passed across a desiccating agent like silica gel or concentrated sulfuric acid. Jensen (82) used a similar method but dried the stream of air by cooling it to -75° C.; he then adjusted the temperature of the air to -30° C. before passing it over the tissue. Kellogg (89) received a patent for a process whereby a frozen food product was fed into an air stream heated to 176° C., and the frozen water was vaporized while the material was still in suspension and before the frozen water returned to the liquid phase.

Lewin and Mateles (105) found that freeze-drying without vacuum was most feasible for several food products when the temperature of the air stream was -4 to -1° C. According to Jensen and Kavaljian (83) the moving air type of freeze-drying decreased the length of time

required for dehydration, but it was detrimental to easily oxidizable compounds. Changes recommended were as follows: using high purity nitrogen instead of air and warming the product to room temperature before removal from the apparatus.

Epstein and Tousimis (50) produced freeze-dried specimens by using only a mechanical pump for sublimation of the ice. The method was said to have decreased the length of time and the amount of handling required as compared with other freeze-drying methods. Eranko (51) freeze-dried animal tissues using an inner glass tube connected by a ground glass joint to an outer tube and a two-stage mechanical pump for evacuating the space between the two tubes. Both the tissue and the vapor trap were cooled with refrigerating agents. The design was based on the principle of short-path condensation.

Electrical techniques have been used to speed the process of freeze drying. Jackson et al. (81) found in the case of peaches that the efficiency of heat transfer limited the drying rates and that the rates of drying produced by different heating methods were as follows (in descending order): dielectric heating, infrared radiation, double plate heating, and single plate heating.

Copson and Decareau (34) used microwave energy at 2450 mc. to supply heat directly to inner ice volumes due to the uniform generation of heat by energy at this frequency. Muscle, bone, and certain other tissues could be dried at faster than normal rates.

Lundquist (112) used thermal infrared radiation as a heat source, while Leatherman and Stutz (102) used dielectric heating.

Bradbury (24) and Decareau (43) used high frequency electric fields. Pearse (147) used thermoelectric heating in a freeze-drying process.

The accelerated freeze-drying described by Ingram (80) used expanded metal sheets between the heating plates and the surface of the food to provide better egress for water and to get heat into the food at the same time. The temperature of the food was raised to 60° C. in the latter stages of drying because no oxygen was present, and the plate temperature could be higher, since it did not contact the food. Gooding and MacDougall (63) used the process successfully for the freeze-drying of both meat and vegetables.

Rhian et al. (157) designed a continuous freeze-drying process in which material frozen as pellets was fed into the apparatus, and dry pellets were removed without interrupting the drying process. The process could be controlled and adjusted by varying the diameter of the pellets, the rate of sublimation, the density of the load in the dryer, and the solids content of the pellets.

Smithies (177) developed a process which was used for large scale freeze-drying. The process used conventional pumping equipment and a vacuum chamber fitted with closely spaced blackened shelves heated with electricity or hot water. The material to be dried was supported on an aluminum tray between but not in contact with the shelves. Heat was transferred by radiation and was regulated by a thermostat which controlled tray temperature. Meat slices 3/8 to 3/4 in. thick were dried in five to twelve hrs. When used with spiked

plates, one-in. slices were dried in about six hrs. Another large scale method described by Record and Taylor (153) used the evaporative spin-freeze principle.

A method described by Rey (155) for the automatic regulation of the freeze-drying of complex systems was based on the fact that electrical resistance was a reliable index of the inner changes in a frozen system and that a "plot resistance" which would control the operation could be determined for a system. Andrew and Hale (1) described a temperature regulator incorporating a thermistor and a direct current amplifier.

Luyet and Williams (116) described a case of pseudo freeze-drying (mere drying at low temperatures of the non-frozen parts of a frozen specimen) for frog muscle tissue. Dehydrofreezing (drying followed by freezing) was described by Talburt (196,197). These cases were examples of variations on the freeze-drying process.

Lambert and Marshall (99) found that the variables of energy input and sample loading governed the rate of freeze-drying, while the variables of total pressure, condenser temperature, and structure and type of freeze-dried solid affected the drying temperature level. They found that molecular diffusion was the primary mass transport mechanism involved, that nonuniform drying rates should be avoided, and that good dryer performance depended on good thermal contact between sample and container, minimum spacing between evaporator and condenser, and adequate pumping capacity. Mink and Sachsel (133) found that for radiation

and conduction freeze-drying systems heat transfer, not mass transfer, was the principal factor limiting drying rate.

According to Malmstorm (117), the rate of dehydration depended on sample temperature, pressure over the sample, partial pressure of water at the trap, radius of the unit's tubing, and the length of the path from the sample to the trap. They concluded that an efficient freeze-drying apparatus for small pieces of tissue should have pumps capable of giving a pressure of 10^{-5} mm. of mercury, a sample temperature above -40° C., a condenser for water at about the temperature of liquid nitrogen, a tubing radius greater than 3 cm., and a path between sample and condenser less than 4 cm.

Lusk et al. (114) found that drying rates increased with increasing platen temperature. Material frozen in liquid nitrogen required a longer drying time than material frozen in an air blast freezer. Chamber pressure did not affect drying rate. Becket (16) found that drying rate was essentially linear until about 95 per cent of the water had been removed and then became exponential. With regard to temperature level during the drying process, freezing within the range of the eutectic zone was highly important in influencing the quality of the final product (210).

According to Saravacos (166), thermal conductivity of material being freeze-dried was affected by pressure, type of gas in the chamber atmosphere, and structure of the material. Thermal conductivity was not significantly affected by drying temperature or amount of absorbed

water in the material. Lusk (113) found that thermal conductivities observed during actual drying were in good agreement with results reported for freeze-dried tissues.

Freeze-drying has found many uses other than the production of food products. A few of these uses were listed as follows: the preservation of human spermatozoa (172) and corneal tissue (229); the processing of pharmaceuticals (90) and vaccines (138); the preservation of pollen (178); and the preservation of the properties of bacteria (26), yeasts (144), and fungi (39); the fixation of histological specimens (64) and the preparation of electron microscope mounts (158); the recovery of water from urine (208); and the freeze-drying of entire biological specimens (69).

In a survey of the application of freeze-drying methods to different plant tissues Jensen (84) found greater differences between types of tissue than between species. Regardless of species, leaf tissue was the easiest to freeze-dry, and root tips were the hardest tissue to freeze-dry. In all tissues except leaves, 1 to 4 mm. segments were optimal for freeze-drying, although 4 mm. segments could sometimes be used.

Several effects of freeze-drying on food materials have been noted: decrease in tenderness when compared with non-freeze-dried tissue (132); severe cell damage (due to ice crystallization) in the central zone of a block of tissue (171); loss of aroma and other volatile compounds (86); and susceptibility to the uptake of oxygen, water,

and foreign flavors (80). The possibility of the preservation of the viability of biological materials was said to be one significant effect of the freeze-drying process (141,145).

II. THE EFFECT OF FREEZING ON BIOLOGICAL MATERIAL

The three fundamental conditions which must be met in the preservation of foods by freezing were said to be a sound product, rapid freezing, and constant storage temperature (135). Dehydrofreezing, still air freezing, air blast freezing, and freezing by immersion in a substance with a low freezing point are four of the several means of freezing (204).

A patent was granted to Noyes (142) for an unusual freezing method. The technique consisted of coating the surfaces of the container which would contact the foodstuff while it was being frozen with a solution having a freezing temperature much lower than that of the foodstuff, introducing the food into the container, quick freezing the food, adding heat to the outside container surfaces, and removing the frozen foodstuff from the holding container.

The physical mechanism of the process of freezing in plant cells has been widely discussed. Asahina (6) found that plant cells, whether alive or not, could easily remain unfrozen at temperatures below -10° C. Without ice seeding of the tissue spontaneous freezing could occur only at a much lower temperature than the freezing point of the tissue fluid. If the natural water content existed, the vitrification of plant tissue was difficult. As a rule inoculation with an ice crystal

was a prerequisite for the initiation of freezing in the cell which was not in the supercooled state. Thus the vacuole sap could usually be frozen at about its freezing point, even in the living cell. The cell froze extracellularly or intracellularly, depending on whether or not the freezing was prevented by the surface layer of protoplasm. Frost hardy cells were characteristically resistant to the penetration of ice crystals. On the surface of these cells large ice crystals usually developed due to the high water permeability of the cells; unhardy cells easily froze intracellularly. If inoculated with ice at a temperature slightly lower than their "freezing temperature," they also would freeze extracellularly. When ice penetrated only the cell wall but not the surface layer of protoplasm, ice formed between them, causing frost plasmolysis. Every case in which the cell was supercooled in the presence of ice on the surface favored intracellular freezing. Intracellular freezing was almost always fatal because of the invariable occurrence of freezing in the protoplasm. The mode of injury in slowly frozen cytoplasm was probably a cytolysis due to mechanical tears by ice formation. Death in rapidly frozen cytoplasm was thought to be due to a strong dehydration caused by the omnipresence of very small ice crystals. The main cause of killing by extracellular freezing seemed to be a dehydration injury, an irreversible coagulation brought about during freezing but not during thawing. Death in plant cells after a long period of freezing may have been attributable to changes in their metabolism at low temperatures.

Persidsky (148) found a periodical propogation of the ice phase in aqueous solutions. A cycle of recurring motifs or "periodicity units" consisting of two transparent zones alternating with two opaque zones was found.

According to Marshall (122), one theory of the process of plant tissue freezing was based on the cell permeability theory and on the thermodynamics of moisture in porous media. The nature of the temperature-versus-time curve during freezing was determined by the speed of advance of the ice front into the tissue.

In work with the freezing of insects, Salt (161) found that the construction of ice-crystal nuclei was heterogeneous in nature (built on a non-aqueous substrate). The probability of nucleation was strongly temperature-dependent, the relationship being a composite of probabilities for construction, survival, and growth of nuclei. Time played a dominant role because nucleation depended on chance orientations of molecules. Surfaces influenced nucleation by providing sites for heterogeneous nucleation, by restricting molecular motion, by providing areas whose energy values differed from those within a mass of water, and by their modifying effect on foreign nucleating agents present in the water. Negative pressures produced by sudden impacts could produce freezing in plain water by momentarily raising the freezing point.

In contrast with the physics of rapid drying, the physics of rapid freezing is not well understood. As the cooling rate of aqueous systems was increased beyond a critical value, there seemed to be an

abrupt transition in the type of solidification that occurred. The physical nature of this transition was not well understood, but theoretical and experimental tools for the calorimetric investigation of phase transformations during rapid cooling and warming have been developed. This information, together with electron microscope information and diffraction data, should ultimately allow the characterization of rapidly frozen aqueous systems (181). Enthalpies determined for the freezing of foods should also prove helpful (120).

According to Meryman (129), one of the most significant causes of cellular injury from freezing was the injurious chemical effect of high electrolyte concentrations resulting from the dehydration inherent in freezing. When freezing was too slow, injury probably resulted from an excessive exposure to temperatures at which adverse chemical reactions could proceed at a significant rate. High rates of cooling also produced injury by a mechanism which was not understood. An optimal rate of cooling was not difficult to achieve, and large volumes of material could be handled by manipulation of the conditions of freezing. The problems of heat exchange during thawing were adverse, and it was hard to obtain high thawing rates in any but small specimens with high surface area-to-volume ratios. The addition of protective agents made the conditions of thawing less demanding and permitted the handling of larger volumes with efficient principles of heat exchange. Glycerol in relatively large concentrations permitted slow freezing and thawing by virtue of its ability to prevent the freezing of most

of the water present, thus reducing the degree of dehydration and electrolyte concentration. Successful applications of the rapid freezing technique have been very few.

According to Lovelock (109) ice crystals and the increase in salinity were important in the survival of frozen cells. The beneficial effect of glycerol was thought to be due to its action as a "salt buffer." The low permeability of other compounds accounted for their poor protection against the intracellular concentration of salts during freezing.

According to Trump et al. (205), the degree of alteration in cytoplasmic organelles and subcellular systems depended on the type of freezing and thawing. Alteration was said to be minimized by slow freezing and rapid thawing, particularly in the presence of glycerol or dimethylsulfoxide. Freezing and thawing type of injury could be induced by other types of cellular injury. The limiting factor in cell survival may have been the sensitivity of cellular membranes. Cells and tissues frozen slowly were greatly distorted by intracellular alterations after thawing. Dimopoullos (46) found that freezing and thawing caused a destruction of cellular integrity.

According to Mazur (125), the survival of various cells subjected to low temperatures was higher when they were cooled slowly. This was consistent with the theory that slow cooling decreased the probability of intracellular freezing by permitting water to leave the cell fast enough to keep the protoplasm at its freezing point. The

relation between the amount of water in a cell and its temperature was expressed as a differential equation involving cooling rate, surface-to-volume ratio, membrane permeability to water, and the temperature coefficient of the permeability constant.

Heard (71) found that large nuclear and extranuclear ice crystal spaces were observed in slowly frozen tissue. Mazur (124) found that when yeast cells were cooled rapidly to -30° C. or lower, fewer than 0.01 per cent survived. When cooled slowly, up to 50 per cent survived. The effect of cooling rate on survival was reflected in the appearance of the cells both before and after thawing. The appearances were consistent with the view that intracellular ice formed to a greater extent in rapidly cooled cells and was responsible for their higher mortality. Kiseleva (92) found in working with tumor tissues that the most favorable results were achieved by combining slow freezing with rapid thawing. Rapatz and Luyet (152) found that the size of ice crystal masses decreased as rate of freezing was increased in both glycerolated and non-glycerolated frog's blood.

Lee et al. (103) found there were insignificant differences for the texture of strawberries frozen rapidly, slowly, and at intermediate rates. Kethley et al. (91) found that the optimum conditions for freezing fresh strawberries were as follows: ten to fifteen min. in air at -34° C. with a linear velocity of 200 ft. per min., or ten to fifteen min. in an immersion freezer at -21° C. with agitation.

With regard to the effect of different freezing methods, Marion and Stadelman (121) found liquid, plate, and air blast freezing gave

no significant difference in the texture and drip of chickens. Barrie et al. (13) reached the same conclusion for blast-frozen and liquid-frozen turkeys. Leader (101) found that the rate of freezing was not as important as prior dehydration in the case of freezing damage in larvae.

Deatherage and Hamm (42) found that quick freezing and thawing caused a smaller decrease in the water binding capacity of meat than did slow freezing. Davis et al. (40) found that supercooling or the addition of finely divided calcium carbonate but not the addition of glycerol decreased freezing damage to the texture and water binding properties of cooked egg white.

With respect to quality of frozen foods, Sweeney et al. (187) found that frozen strawberries were highly variable in texture. Longree (108) found similar results for potatoes and for apricots.

Winter et al. (217) found that the texture of frozen strawberries was better when they were stored at a constant temperature than when storage temperature fluctuated. Hanson et al. (67) found that the composition of starch-thickened foods could be varied, enabling the foods to better withstand frozen storage.

III. DEHYDRATION OF FOOD PRODUCTS

"Dehydration" means "the removal of water." Therefore, in a strict sense, most of our present food products are at least partially dehydrated. Primitive peoples dried many different foods. Some peoples

in cold climates hung foods out in the cold to dry by sublimation and were the first users of the technique of freeze-drying (17).

Drying was first used for preservation alone but is now used largely because of the convenience factor. In the 1930's the state of the art was primitive, but World War II, with its need for saving of weight and space, led to many drying advances (48,170). By 1947 about 2000 patents had been issued in the United States for dehydration processes (17). Dehydration processes must represent advantages for transportation or preservation in order to be competitive with canning (14).

Gooding and Rolfe (62) used a vacuum contact plate dehydrator as a freeze-dryer during the first two hours of the cycle and then used higher temperatures during the remainder of the cycle. This process produced dehydrated foods which had most of the characteristics of freeze-dried foods but which required only about half the time for drying. The modification which was made allowed the development of a much better vacuum in the apparatus (68). The most needed advances in drying, according to Van Arsdel (206), were improvements in completeness of reconstitution, improvement in the retention of original flavor, and solution of difficulties caused by the development of oxidized off-flavors.

There are many methods for the dehydration of foods. A few are as follows: sun drying (209); drying with radiant and direct heat (18); treating with a water solution of trichloroacetic acid (22);

and the use of dehumidified air, a method known as aphydatosis (27, 28). Nelson et al. (139) found no difference in quality between the two techniques of drying which they studied.

Saravacos and Charm (163) found that a small increase in drying rate during the constant-rate phase was brought about by increasing the air velocity or decreasing the air humidity but that these variables did not affect the falling-rate period. Drying time was found to be proportional to the square of the thickness. Drying during the falling-rate period was thought to be due to molecular diffusion. Diffusivity of moisture was found to follow the Arrhenius equation. Stephenson (181) found that the reduction in drying rate caused by a given thickness of dry shell could be characterized quantitatively by the drying factor. Yao (224) found that tray temperature, drier pressure, initial product temperature, and mode of heat transfer affected the rate of drying. Saravacos (164) found that surface active agents had no effect on drying rate or rehydration characteristics. Copeman (33) found that dehydration caused significant losses of many mineral elements. Nitrogen loss was the smallest of the losses for the elements studied. The behavior of water in dehydrated foods could be studied by evaluating the relationship between equilibrium relative humidity and moisture content by a vapor pressure measurement (200).

IV. FOOD TEXTURE

A consumer awareness study showed that texture was the most often mentioned of the three food quality attributes (flavor,

appearance, and texture). Texture was especially conspicuous in bland foods or in foods designed to be crunchy or crisp (192). Matz considered texture to be the second most important food quality attribute, with appearance being first. Generally those foods eaten in largest quantities by all cultures were white in color, soft in texture, and bland in flavor (123). Texture was important in the concepts of desirable maturity in vegetables and ripeness in fruits (96). Texture was found by Carlson and Hoelzel (29) to influence certain dietary habits of rats. Food texture influenced the discernment of taste substances (119).

"Texture" was derived from the Latin verb "to weave" and was probably first applied in the English language with reference to fabrics (123). Webster's dictionary defined texture as "the disposition or manner of union of the particles of a body or substance" (96).

Texture was the least well described food quality attribute, probably because of the lack of a bridge between theoretical and practical rheology and because of the restricted nature of most texture work. Texture has been defined in terms of hardness or softness of kernels, rigidity of solid units, consistency or "body," toughness, stringiness, slicing quality, crispness, visual appearance of the fineness of grain, and mouth feeling of fineness of grain. All of these definitions have referred to specific food products (193). A committee of the Institute of Food Technologists (1959) defined texture as "those properties apprehended by the eyes and by the skin and muscles of the

mouth" (123). Kramer defined texture as those sensations perceived by the sense of feel only and as that part of rheology dealing with the deformation of matter by forces greater than gravity (96). Under this definition the sense organs that perceived texture were: (1) receptors in the hard and soft palate, tongue, and gums (smoothness, roughness, stickiness, and slickness); (2) receptors in the roots of the teeth (elasticity and brittleness); and (3) receptors in the muscles and tendons of mastication (elasticity, brittleness, and viscosity) (123).

A classification based on the deformation and flow of matter as perceived by sight and as caused by forces greater than 1.0 gravity was one way of subdividing textural characteristics (96). Another system of classification divided textural characteristics into primary and secondary characteristics. Primary characteristics were as follows:

1. Mechanical characteristics--reaction of food to stress.
2. Geometrical characteristics--arrangement of constituents
3. Other characteristics--mainly water and fat content.

The mechanical characteristics were hardness, cohesiveness, viscosity, elasticity, and adhesiveness. The geometrical characteristics were particle size and shape and particle shape and orientation. Other characteristics were water and fat content (oiliness and greasiness). This system lent itself to instrumental and organoleptic use and made possible the establishment of a correlation between the two (193).

Both ordinary sensory testing panels and special panels of experts have been used for the subjective evaluation of texture (123).

At the General Foods Research Center, a conventional testing panel was used to develop a standard rating scale for the mechanical parameters of texture. Based on individual responses to product texture, numerical scales for hardness, brittleness, chewiness, gumminess, adhesiveness, and viscosity were constructed by assigning numbers to an array of foods which covered the popular range of intensities of each characteristic (194). Organoleptic methods were used by Zaehringer et al. to evaluate the mealiness of steamed potato cubes (227).

The standard rating scales for texture were used by Szczesniak et al. (194) to determine a texture profile for various products. The method, based on the A. D. Little flavor profile as a model, required a trained panel with knowledge of the texture classification system and the standard rating scales. Foods were characterized by numbers (based on standard rating scales) for mechanical and geometrical characteristics perceived at the first bite and during chewing for changes made during mastication. The method was useful because it made possible the collection of descriptive and quantitative sensory data on textural characteristics and because it was flexible (25). The expert panel technique of texture evaluation has also been used for distinguishing between softness, friability, and tenderness of connective tissue of beef steaks (35).

The objective measurement of texture could be considered to be divided into fundamental, empirical, and imitative tests. Empirical tests have been the most widely used of the three (195).

Fundamental tests measured rheological properties such as viscosity and elastic modulus. The measuring instruments were of essentially two types: the dashpot (used for Newtonian liquids), and the metal spring (used for Hookean solids). Since foods were complex systems with respect to their rheology, banks of these instruments were often hooked in series or in parallel to measure delayed deformations or elastic effects (195).

Before beginning a survey of the empirical means used to measure food texture, it would be helpful to examine some definitions which were applicable:

1. Stress--an applied force (195)
2. Strain--the resultant deformation due to applying a stress (195)
3. Compression--a reduction in volume and a change of shape without division of the object in question (96).
4. Tensile strength--the antipode of compression strength; the force required to pull an object apart (96).
5. Cutting force--the force required to divide an object into two or more parts without changing the shape of the parts (96).
6. Shearing force--the force necessary to cause two contiguous parts of the object to slide relative to each other in a direction parallel to their plane of contact (96).

Empirical instruments for measuring food texture were classified as penetrometers, compressors, consistometers, shearing devices, and miscellaneous instruments (195).

Penetrometers usually measured the pressure or force to drive a plunger or cone to a certain depth into a product or the depth to which a given force or pressure would drive a plunger or cone. Examples were the Bloom gelometer, the Boucher jelly tester, the ASTM grease penetrometer, the plumit (195), and the fruit pressure tester (96,195). A penetrometer utilized both shear and compression forces. The relative importance of each could be adjusted by manipulating the perimeter-to-area ratio of the punch used (23).

Compressors were quite variable in form and operation. The Delaware jelly tester measured susceptibility to compression by the extent to which a given air pressure could force the plunger of a syringe into a given volume of the material. The Brinnell hardness tester was used to calculate a hardness index on the basis of certain parameters associated with the forcing of a steel ball into a surface. The Caffys and Baron cheese tester measured cheese texture on the basis of the extent to which a metal hemisphere could be forced into the cheese by a given pressure. The Baker compressimeter and the Platt bread tester measured the extent to which bread could be compressed. The General Foods gel characterization apparatus used strain gages to measure the force necessary to deform a gel (195). Hydraulic pressure testers have been used to measure the water-holding capacity of cooked ground lean meat (7) and the hardness of Dungeness crab meat (38).

The use of consistometers to measure viscosity did not fit under some definitions of texture (96), but a survey of such instruments and

their use was valuable due to the fact that many workers considered viscosity to be a component of texture (195). Consistometers were used to measure the viscosity of liquids and of semisolids. The Bloom consistometer measured the relative pressure necessary to force a substance through a hole in the end of a plunger (195). The Bostwick consistometer measured the distance catsup traveled down a trough at 20° C. after release by a trap (123,195). The MacMichael viscometer measured the force in a wire which was necessary to hold an inner cup stationary as an outer cup containing the fluid was rotated (195). The Brookfield viscometer measured the force necessary to rotate a paddle in a cup containing the material to be tested (123,195). Several viscometers were based on measurement of viscosity by the length of time required for the substance to flow a given distance in a tube (30,123).

Shearing devices were used to evaluate the tenderness of meat, fish, and vegetables. The Warner-Bratzler shear mechanism was used to determine the maximum force necessary to shear a core of meat (placed in a hole in the blade of the instrument) by two shear bars. The pea tenderometer measured the force necessary to shear peas between two standard grids. The disadvantage inherent in this method was that it only furnished an average value (195). The Kramer shear press measured (by means of a ring dynamometer) the force required to drive shear bars through a box (containing the product) with corresponding slots (2,195). One cell that was used simulated the compression and

shearing action of teeth; another cell measured fibrousness by cutting action; and a third cell measured juiciness (195). The coefficient of variation of replicate determinations for the shear press compression values on uniform cubes of foam plastic was found to be 2.1 per cent (3).

Several miscellaneous instruments were used to evaluate food texture. The succulometer measured juiciness in terms of the volume of liquid expressed per weight of material by a given pressure. The food mincer measured the amount of work to grind a given amount of food to a given particle size (195). The fibrometer was used to measure the toughness of asparagus. Results were expressed in terms of the length of asparagus that could be cut by the force due to applying a three-pound weight to a standard wire (95,195,215). The elasticity coefficient of peas was determined by how far the peas bounced when dropped onto an inclined plane from a given height (rebound range). The standard deviation of the rebound range was reported to be a good measure of the variation in texture of a batch of peas (37). Bulk density (98) and a standard cooking method (100,228) were used as measures of texture.

Probably the best way to measure texture was to use a device which approximated as closely as possible the action of the consumer which would generate a sensation of texture. A synthetic mouth would be desirable but would be very expensive and hard to calibrate (96). The Vodlokevich bite tenderometer (195), the Massachusetts Institute

of Technology denture tenderometer (151,195), and the General Foods texturometer (58,195) were attempts to utilize this theory of texture testing. The butter spreader measured the force necessary to extrude and cut a cube of butter. The Brabender farinograph measured the torque exerted by a given quantity of dough while being kneaded. The alveograph measured the work done in forming and bursting an air bubble in dough. The Brabender amylograph measured the viscosity of a paste during cooking (195).

V. WATER IN BIOLOGICAL SYSTEMS AND THE REHYDRATION OF FREEZE-DRIED FOODS

The action of water in foods is largely due to its characteristic bond angle of 104°31' rather than the 109°28' tetrahedral angle. Water molecules may interact due to electronic interaction, dispersion forces, repulsive forces, and delocalization interaction. The hydrogen bond has a bond energy such that the bond is readily broken at ambient temperatures. However, a structure may be stabilized over a wide range of temperatures if cooperative hydrogen bonding occurs in a regular manner. Water molecules may interact with different grouping, among them ionized groups, polar non-hydrogen bonding groups, and non-polar groups (211).

There were six factors believed to influence the rehydration of freeze-dried muscle tissue: orientation of muscle fibers, thickness of sample, temperature of rehydrating solution, pH of rehydrating

solution, and pressure of the atmosphere in which rehydration was carried out. Rehydration was faster in transverse than in longitudinal samples. Demineralized water was found to be better for rehydration than hypertonic solutions (8).

Water of rehydration penetrated through large tissue cavities between fibers in slowly frozen tissue and through small cavities within fibers in rapidly frozen tissue. Water penetrated more freely through solid parts than through cavities. Most of the water reabsorbed by single fibers entered during the first three seconds after flooding. After having imbibed water the solid parts swelled into the cavities, and entrapped air was dissolved or expelled. Air in the small cavities of frozen tissue was rapidly removed, but the air in cavities of intermediate size in slowly frozen tissue was a major obstacle to the completion of rehydration. The air in the large channels of slowly frozen tissue was rapidly expelled by the onrush of water. Water did not enter cells from a longitudinal direction. There was a gradual increase in opacity following rehydration (115).

Hamm and Deatherage (66) found that freeze-drying of beef resulted in a drop of water-holding capacity only in the isoelectric point range. It caused a tighter network of protein structure, probably because the peptide chains lay more closely together after drying. The tighter structure may have been stabilized by the formation of new salt or hydrogen bonds.

Deatherage and Hamm (42) found that quick freezing caused a very small but significant increase in the water holding capacity of

meat. Slow freezing caused a significant but small decrease of the water holding capacity of meat.

Litwiller and Pettit (106) found that dehydrated Blue Lake green beans which had been prefrozen rehydrated much more completely than those dehydrated without prefreezing. Roseman (159) found that milled and unmilled rice frozen in the presence of 60 per cent or more water in the grain underwent structural changes which resulted in very rapid rehydration at room temperature.

Wuhrmann et al. (223) found that freeze-dried vegetables had faster rehydration rates and higher uptake ratios than those conventionally dried. Nemitz (140) found that freeze-dried bulbs differed only slightly from warm air dehydrated ones in water reabsorption ability. Freeze-dried beans, asparagus, and mushrooms reached a higher reconstitution grade than the corresponding warm-air-dried vegetables. Saravacos (165) found that the water absorption isotherms of freeze-dried gels at 30° C. were similar to the isotherms of air dehydrated materials. The rates of water absorption and desorption were high, and they increased at low water contents. Thomson et al. (202) found that five months of storage of freeze-dried beef samples caused a deterioration in rehydratability. Tappel et al. (199) found that freeze-dried beef rehydrated readily to give a product having all the essential properties of fresh meat.

Saravacos and Stinchfield (167) found that for freeze-dried foods the absorption of water was at a maximum between 10° C. and

30° C. The equilibrium vapor pressure followed the Clausius-Clapeyron equation throughout the temperature range studied. Shimazu (174) found that rehydration occurred more rapidly for freeze-dried tissues than for any of the other drying regimes studied (high-, medium-, and low-temperature drying and freeze-drying).

Younger (225) found that precooked lamb in both the freeze-dried and the rehydrated states resembled fresh meat more closely than uncooked freeze-dried meat. Ballantyne et al. (11) found that freeze-dried meat which had been previously cooked in a pressure cooker rehydrated more rapidly than freeze-dried meat which had been cooked with dry heat.

Wismer-Pedersen (219) found that magnesium or calcium ions increased the hydration capacity of freeze-dried myofibrils, as did a relatively high pH. Suden et al. (186) found that the extent of rehydration of pork muscle was not influenced by the pH of the rehydrating solution, the pH of the rehydrated meat, or the fat content of the meat. Wismer-Pedersen (220) found that injecting pork loin with ethylenediaminetetraacetic acid and pyrophosphate at a concentration of 10 millimoles per 1000 gm. of meat and then freeze-drying the meat gave an improved rehydration capacity as compared with conventional, freeze-dried pork loin.

Sterling (184) found that the rehydrated volume of carrots increased with blanching and decreased with storage time. Rehydration was inversely related to cellulose crystallinity. Baker et al. (10)

found that demethylated citrus pectin gave good rehydration swelling when used in simulated fruit preparations.

Anglemier et al. (4) found that in the case of freeze-dried ham the muscle fibers perpendicular to the largest surface areas showed higher levels of rehydration and juiciness than parallel fibers. Cooley et al. (32) found that calcium chloride added to rehydration water improved rehydration speed and completeness. Simon et al. (175) reached much the same conclusion.

Nury et al. (143) found that rapid hydration of fruits was caused by heating the fruits in steam or boiling water and then immersing the fruits in cold water. Crean (36) found that the incidence of peas which were slow to rehydrate was directly related to initial moisture content. According to Mossel (136), macromolecular substances contributed to water retention in biocolloids. Probably the most important effect of poor rehydration in freeze-dried foods was that such a product had poorer tenderness and appearance than a comparable fresh food product.

VI. COMPOUNDS USED TO PREVENT FREEZING DAMAGE

Samygin and Matveeva (162) found that solutions gave protection to biological material during both fast and slow freezing. During rapid freezing the solutions protected cells from the formation of ice; during slow freezing they protected cells from the adverse effects of dehydration by extracellular ice. In both cases protection was

linked with cell plasmolysis prior to or during freezing. Solutions with high eutectics failed to protect cells because the plasmolyzed protoplast was deformed between invaginated cell walls. This invagination was probably caused by non-uniform pressure of extracellular ice on cell walls. As solutions increased in concentration the protective effect was increased due to the decrease in the amount of water released with a given drop in temperature.

The protective action of glycerol was due to its ability to prevent electrolyte concentration from rising above the level which would cause irreversible damage (110). Dimethylsulfoxide was approximately equal to glycerol in protecting against damage during freezing and thawing but was somewhat more toxic during storage (54,69). Other substances used to prevent freezing damage were sodium alginate (196), pyridine N-oxide (118), and serum albumin (168).

VII. COMPOUNDS USED TO IMPROVE THE TEXTURE OF FRUIT PRODUCTS

Wegener *et al.* (213) found that low methoxyl pectin, a kelp extractive, and an Irish moss extractive increased the firmness and improved the appearance of Tennessee Supreme strawberries in sirup and dry sugar packs. Low methoxyl pectin had the greatest firming action at lower levels. Levels of 0.1 to 0.2 per cent pectin were found to be best. A water dispersion of the colloids was found to be preferable to a dry mix.

Murphy et al. (137) found that 0.15 per cent low methoxyl pectin increased drained weight by 10 per cent in the case of several varieties of strawberries frozen in 60 per cent sirup. However, the pectin produced no detectable effect on the sensory qualities of texture, flavor, and color.

Hanson et al. (67) found two general ways to improve the texture stability of frozen foods under frozen storage conditions. Additives such as pectin, gelatin, gums, and Irish moss extractives could be used, or the amount of liquid could be decreased.

The selection of the proper gum for a certain consistency effect could be made by reference to the shape of the viscosity-versus-rate-of-shear curve. As sliminess in the mouth decreased, there was an increasing deviation from Newtonian character (191).

A patent issued to Lloyd (107) was based on placing fruit into a container and applying starch conversion sirup solids in finely divided form to the upper surface of the fruit. Loss of juice was claimed to be minimized.

Pectinate and pectate coatings for improving the texture of fruit products were best prepared by combining pectins with a methoxyl content of 4 per cent or less with a thirty-sec. treatment with 1.66 per cent calcium chloride (131). Sucrose mixed with low methoxyl pectin was used (188).

Collins and Wiley (31) found that calcium lactate and calcium gluconate increased apple slice firmness but did not affect sloughing or wholeness. Magnesium salts did not affect slice firmness.

Infrared spectra were used commercially to distinguish between high methoxyl pectins, low methoxyl pectins, and polygalacturonic acid (154). Carrageenan, furcellaran, fucoidan, and other hydrocolloids formed precipitates when mixed with thiazine, oxazine, azine, and other cationic dyes. The reaction was thought to require the sulfate polygalactose moiety. Salts and low pH's inhibited formation of the stringy precipitate. The precipitate may have formed due to the tendency of linear macromolecules to agglomerate into fibers on precipitation from solutions (65). Potassium salts have been found to decrease the viscosity of lambda-carrageenan dispersions (226). Colloids used for texture improvement were best preserved under vacuum or in a nitrogen atmosphere (144).

Gum guar was processed from a leguminous plant called Cyamopsis tetragonoloba, which was grown extensively in Pakistan. The seed coat was removed by passing the seeds rapidly through heat and then subjecting them to a pearling operation. The endosperm was freed from the germ and was then classified, sized, and blended. Gum guar swelled almost completely in cold water. It was insoluble in organic solvents. The rate of hydration was directly proportional to the temperature of the water as well as to the particle size of the gum. These factors determined the speed at which maximum viscosity was reached. The rate of swelling was affected by pH as well as dissolved substances. Gum guar was said to be essentially a polysaccharide composed of a straight chain of D-mannose with a side chain of one D-galactose on approximately

every other mannose unit. The molecular weight was said to be about 220,000 (126,127).

Kraft Kraystay Type K was made of carrageenan and of vegetable monglycerides and diglycerides. It was dispersible in cold water, resulting in solutions of substantial viscosity. The viscosity did not increase on standing (93).

Algin (the Kelco Company) was the general term for the hydrophilic derivatives of alginic acid, a natural colloid extracted from several types of brown seaweed. Alginic acid was a colloidal polyuronic acid composed mainly of anhydro-beta-D-mannuronic acid residues linked in the one to four position to form a long straight chain molecule. Algin produced a high viscosity in aqueous solution at low concentration. The viscosity of an algin solution depended on polymer size, concentration, temperature, other substances in solution, and rate of shear. The molecular weight of commercially available algin ranged from 32,000 to 200,000, which corresponded to a degree of polymerization of about 180 to 930. Differences in manufacturing gave algin products with a wide range of viscosities (88).

Sodium carboxymethylcellulose (sodium CMC) was an anionic, water-soluble polymer derived from cellulose. It was used as a substitute for the natural gums and was known for its physiological inertness, solubility, and film-forming ability. Chemically, sodium CMC was the sodium salt of carboxymethylcellulose formed by the reaction of soda cellulose with the sodium salt of monochloroacetic acid. The reaction was represented as:

$$RONa + ClCH_2COONa \longrightarrow ROCH_2COONa + NaCl ,$$

where R represented cellulose. A side reaction competed for the basic raw material; sodium monochloroacetate was converted to sodium glycolate. The principal reaction byproducts were sodium chloride and sodium glycolate. The basic variables responsible for differences in properties were degree of polymerization, degree of carboxymethyl substitution, uniformity of carboxymethyl substitution, degree of refinement, and physical form. Solutions were pseudoplastic, meaning that viscosity decreased with increasing rate of shear (49,72).

Corn sirups were noncrystallizable, clarified, concentrated aqueous solutions produced by the partial hydrolysis of corn starch into a mixture of the sugars glucose and maltose plus higher polymers of glucose. Corn sirups were classified by dextrose equivalent (a measure of reducing sugar content) and Baume' (a measure of specific gravity) (79).

Starvis (made by the Hercules Powder Company) was a food grade of wheat starch which had been precooked, dried, and ground. It developed into a viscous paste when placed in water, forming a gel with high water-holding capacity (73).

Distillation Products Industries made two edible foam stabilizers which could be used in whipped products. These were Myverol Type 18-00 (from hydrogenated lard) and Myverol Type 18-17 from hydrogenated cottonseed oil) (47).

Gelatin was a refined extract of collagenous tissue (white connective tissue). It was insoluble in cold water and soluble in

hot water, and it formed clear, viscous solutions. It was an amphoteric substance, having both acidic groups (carboxyl groups) and basic groups (amino and guanidine groups). The overall charge on the gelatin molecule depended on the pH of the solution and on the other ions which were present. Gelatin formed an almost true solution in water; gelatin solutions tended to lose their strength at relatively high temperatures (189,190).

VIII. THE RELATIONSHIP OF SWEETENERS TO THE TEXTURE OF FROZEN PRODUCTS

Dawson et al. (41) used the following mixtures for freezing halved Wakefield strawberries: 20 per cent sucrose, 40 per cent sucrose, enzymatically hydrolyzed corn sirup, acid hydrolyzed corn sirup, and their own juice. After ten months storage berries packed in sirup made of one part acid or enzymatically hydrolyzed corn sirup and three parts of 40 per cent sucrose were the most satisfactory in texture as judged by a five member expert panel. Talburt et al. (198) found that the substitution of sirup for dry sugar did not substantially reduce the per cent of mushy berries when frozen strawberries were thawed. Sistrunk et al. (176) found that the four strawberry varieties Northwest, Marshall, Siletz, and Puget Beauty reacted differently to freezing. The percentage of mushy slices in the frozen product was lowest in the Northwest variety. Shear-press measurements of firmness were higher than in other varieties. Wherever variation

in time of harvest was involved, there was an increase in the per cent of mushy slices and of water soluble pectin content in the frozen product that was prepared from fruit harvested beyond mid-season. There was a decrease in the viscosity of sirup and in shear press measurements of the firmness of the thawed frozen product. Maturity probably had much to do with the effect of date of harvest. For the Siletz variety an increase in mixing time beyond the time necessary to dissolve the sugar increased the percentage of mushy slices and the sirup viscosity of the thawed frozen slices. Shear press measurement of firmness decreased also. The percentage of mushy fruit increased and the sirup viscosity decreased with holding at either 1° C. or room temperature prior to processing.

Joslyn (85) found that texture was influenced by the degree of inversion of the sucrose used in the packing of frozen fruits. In general sugar sirup containing 50 per cent invert sugar was not a satisfactory packing medium. Bartlett and Hard (15) found that sirup treatment had little effect on texture when sirup treatments of sucrose (cane and beet), three commercial corn sirups, a commercial sucrose sirup, and glucose were used. Bockian and Aref (20) found that drained weight increased with an increase of the fruit-to-sugar ratio.

IX. THE STRAWBERRY FRUIT

Under optimal conditions the leaves, stalks, and young roots of the strawberry plant appeared throughout the entire growth period.

During unfavorable periods normal growth stopped, and irregular growth of the aerial organs became more pronounced than that of the root system. Disturbance of the rhythms of growth and development of aerial organs was more noticeable in older plants, while young plants were more resistant to unfavorable conditions. Strawberries did not tolerate large doses of organic fertilizers or excessive soil moisture. Good care, in particular annual hilling, insured continuous growth of adventitious roots, formation of new shoots, and increases in productivity. Rapid aging of rootstock and dying of roots was checked by the pruning of both the aerial and the underground parts of the bush with simultaneous top dressing, irrigation, and hilling (156).

The Marshall variety was the longtime standard for freezing and preserving. However, several new varieties evaluated by Wolford et al. (222) compared favorably with the Marshall variety from the standpoint of color, flavor, and texture.

If least-cost techniques were used, the bulk of the strawberry crop should be produced in California. However, large-volume shifts to closely competing regions might be expected if future conditions result in cost or price movements adverse to California producers (44).

The cultivated strawberry fruit (Fragaria chiloensis) was said to consist of a receptacle (the edible portion) with ovaries scattered across its surface (78). The receptacle consisted of the pith, the cortex, and the fibrovascular bundles, which were found between the pith and the cortex. The cortical tissue was formed by division of

cells of the hypoderm. Intercellular spaces were found in the cortex and in the pith but never in the hypoderm (218).

Parenchyma cells (thin-walled cells which were held together by the pectic substances) were the main type of cell found in the edible part of the fruit. Parenchyma cells, like other fleshy fruit cells, fit together imperfectly, a condition leading to the formation of intercellular spaces which became filled with gases (9,45,55,214).

Some parenchyma cells had a secondary wall in addition to their primary wall. The middle lamella and the primary wall, which were often indistinguishable, were often grouped together as the "compound middle lamella" (52,55).

Parenchyma cells often exhibited cavities or pits in their primary and secondary walls. A pit in one cell was usually opposite a pit in another cell. A pit could join an intercellular space with a pit membrane separating the two spaces. The pit membrane was thought to be differentially permeable and to allow ions and low molecular weight compounds to pass through it (52,55).

Parenchyma cells were formed mainly from cellulose. Hemicellulose and pectic substances were found (52,55).

The middle lamella was thought to be composed of insoluble pectic substances, probably calcium pectate (53). Softening of tissues was mainly due to two causes, the separation of cells and the softening of cell walls. Cell separation could be caused by the hydrolysis of the pectic substances. The degradation of cell walls caused cell wall softening, which allowed the cells to be easily punctured (130,150, 182,183).

Kao (87) investigated fresh and freeze-dried strawberries by means of autoradiograms and photomicrographs. His histological observations indicated that the fruit was composed of five different kinds of tissue: the epidermis, the hypoderm, the cortex, the vascular vessels, and the pith. He also found that slow freezing (air blast freezer) caused the cell wall to rupture and produced large voids, while a more rapid rate of freezing (Freon Twelve) prevented these detrimental effects.

CHAPTER III

MATERIALS AND METHODS

I. PLANT MATERIAL USED

The Tennessee Beauty variety of strawberries was used in this study. The strawberries were obtained from a commercial grower in Mountain City,Tennessee, and were taken to Knoxville. They were stored overnight at 2° C. and were then processed. Processing consisted of hand washing, hand capping, and removal of all unsound berries (soft, rotten, and molded berries). Most were then immediately frozen by the individual quick freezing technique in an air blast freezer at -29° C. Approximately 4 lbs. of berries were frozen by immersion in liquid nitrogen, and approximately 2 lbs. were frozen by immersion in Freon Twelve. All berries were stored in polyethylene bags at -18° C. in a still air freezer.

II. EXPERIMENTAL DESIGN AND BLENDING METHOD

General Method

The strawberries were allowed to thaw for 30 min. at room temperature so that the experimental mixtures could be comminuted in a stainless steel Waring Blendor with a capacity of 1250 ml. Each experimental batch contained four elements: water (200 ml. per batch except in the case of experiment four, effect of amount of water);

sucrose (20 gm. per batch except in the case of experiment one, effect of amount and type of sugar); stabilizer (1 gm. per batch except in a few cases in experiment five, effect of kinds and levels of stabilizers); and strawberries (enough so that the combined weight of strawberries, sugar and stabilizer was 100 gm.). In addition, calcium chloride at different levels was used with low methoxyl pectin in the pectin portion of experiment number five. In all experiments except number five the stabilizer used was Hercules CMC. Levels of the various factors used were reached by use of the tables in the United States Department of Agriculture handbook by Watt and Merrill (212).

A 140-position rheostat (Central Scientific Company, Chicago) was used with the Waring Blendor. In all cases except experiment number two the blending was done by placing the water in the blendor, turning the rheostat to position fifty, adding the mixed dry ingredients (sugar and stabilizer) by sifting them into the vortex of the water, allowing mixing to proceed for one min., adding the partially thawed strawberries, and turning the rheostat at a rate such that the speed reached the maximum one min. after the addition of the strawberries. Mixing was allowed to take place at maximum speed for three min., and then the puree formed was poured immediately into cellulose wiener casings with a diameter of 26 mm. (East Tennessee Packing Company, Knoxville, Tennessee). The batch size which was used gave a rope of puree about 3 ft. long. Each rope was hung vertically for 30 min. to allow seeds to settle to the bottom and any foam to rise to the top.

The ropes of puree were frozen in an air blast freezer at -29° C. and left there until slicing for freeze-drying.

Each treatment was replicated three times. With the exception of experiment three all strawberries used were berries which had been frozen in an air blast freezer at -29° C. Deaeration of the experimental batch after blending and before placing in the wiener casing was done only in experiment six. The distilled water used in the batches was at a temperature of 30° C. except in the case of experiment seven.

Experiment One: Effect of Amount and Type of Sugar

The two types of sugar used were granulated sucrose and corn sirup (Karo Sirup, clear). With the exception of amount of sugar and type of sugar, the ingredients in the batches and the method of preparation of the samples were the same as the general method described above. The amounts and kinds of sugar were as follows: no sugar, 5, 10, 20, 30, and 40 gm. of sucrose; and 5, 10, 20, 30, and 40 gm. of corn sirup. All figures are on the basis of the standard size batch.

Experiment Two: Effect of Method of Blending

One sample was prepared in which dry Hercules CMC was sifted into the vortex of the water with the blendor operating. For the other sample the same amount of Hercules CMC was dispersed (by stirring) in 5 ml. of 95 per cent ethanol, and this mixture was poured into the

vortex of the water with the blendor operating. In the latter case the volume of distilled water was decreased by 5 ml. to allow for the alcohol added. With these exceptions, the samples were treated according to the general method described above.

Experiment Three: Effect of Method of Freezing of Strawberries

In this experiment strawberries frozen in an air blast at -29° C., in liquid nitrogen, and in Freon Twelve were used in different samples. In all other respects the samples were treated according to the general method.

Experiment Four: Effect of Amount of Water

One hundred ml. and 200 ml. of distilled water were used in different samples. In other respects the samples were treated according to the general method.

Experiment Five: Effect of Kind and Level of Stabilizer

The variables used in different samples were as follows: Hercules CMC, Dupont CMC (P-75S-H), Dupont CMC (P-75-M), Dupont CMC (P-75-L), Dupont CMC (P-75-H), Food Stabilizer GM 246 (Germantown Manufacturing Company), Swift Velatex Gelatin (2.25 gm.), Swift Velatex Gelatin (4.50 gm.), Swift Velatex Gelatin (1 gm.), Pad Guar Gum (Clarence Morgan, Inc.), Meer Guar Gum (1 gm., sifted), Meer Guar Gum (1 gm., dispersed in alcohol), Meer Guar Gum (3 gm., sifted), Hydrolyzed Cereal Solids (Corn Products Company), Kelco Kelgin MV, Kelco Kelcoloid HVF, Kelco Kelcoloid S, Kelco Kelcoloid LVF (1 gm., sifted),

Kelcoloid LVF (1 gm., dispersed in alcohol), Kelcoloid LVF (with 1.37 gm. calcium chloride added), Kelcoloid LVF (with 0.50 gm. of ascorbic acid added), OK Dri Sweet Malto Dextrin (Hubinger Co.), OK Keojel Starch (Hubinger Co.), Snowflake Starch (Corn Products Co.), FTD Starch (Corn Products Co.), Starvis (Hercules Powder Co.), Supercol GF (General Mills, 0.25 gm.), Supercol GF (General Mills, 0.40 gm.), Supercol F (General Mills, 0.25 gm.), Supercol F (General Mills, 0.40 gm.), low methoxyl (or LM) pectin (Sunkist Growers, Inc., 1 gm.; 1 gm. of calcium chloride added), LM pectin (3 gm.; 1 gm. of calcium chloride added), LM pectin (10 gm.; 1 gm. of calcium chloride added), LM pectin (1 gm.; no calcium chloride added), Myverol 18-00 (Distillation Products Industries), Myverol 18-07 (Distillation Products Industries), and Kraystay Type K (Kraft Industrial Division, Kraft Foods Company). With these exceptions the procedures and amounts of ingredients used were according to the general method.

Experiment Six: Effect of Deaeration Following Blending

One sample was deaerated in the blendor immediately following blending and immediately preceding pouring into the casings, and one sample was treated in the ordinary way (no deaeration). Deaeration was accomplished by means of covering the blendor and removing air via a hose connected to a water aspirator. In all other respects the general method was followed.

Experiment Seven: Effect of Temperature of Water

In this experiment the effect of the temperature of the distilled water used in blending was studied. For one sample water at 100° C. was used. In all other respects the general method was used.

III. PREPARATION FOR FREEZE-DRYING

Ropes of puree were taken from storage in a -29° C. air blast freezer. All subsequent work prior to freeze-drying was done inside a -18° C. still air freezer.

Wiener casings were removed with a sharp knife, with the exception of one sample which was formed in an edible casing. A 12 in. length of the rope of frozen puree was taken, beginning 3 in. from the top of the frozen rope. The 3 in. segment from the end of the rope was discarded, and the rest of the rope was stored at -18° C. The 12 in. segment was sliced on a meat-type bandsaw with a bone blade. The slice thickness guide was set at 1/4 in. Each treatment was placed in a hardware cloth basket 5-1/2 in. wide by 5-1/2 in. long by 2 in. deep. Replicate A was placed on the bottom, replicate B in the middle, and replicate C on the top. Each layer was formed of one layer of slices, spaced so that each slice was at least 1/16 in. at the nearest point from surrounding slices. All three layers (replicates) were separated by hardware cloth dividers. Material to be freeze-dried was kept at -18° C. (in still air) until immediately before being placed in the freeze-drier.

IV. FREEZE-DRYING

The freeze-drying unit was a Del-Vac Freeze-Dryer, Model 11212 RVM, made by the American Sterilizer Company. The area of the drying shelf was 144 sq. in., and the depth of the chamber was 6 in. A Freon Twenty-Two coil was used as a condenser to freeze out water vapor.

When the baskets of samples to be freeze-dried were placed in the chamber, the platen temperature was 0° C. After one hr. the thermostat controlling the platen temperature was turned to 38° C. After two hr. it was turned to 93° C., and after three hr. it was turned to 121° C. The slices were removed from the freeze-drier when thermocouples buried in the slices read approximately 54° C. This was taken to be a good compromise between getting the product dry and burning it. Four baskets (four treatments) were freeze-dried in each freeze-drying cycle. Most cycles required eighteen to twenty hr.

V. STORAGE

Immediately after being removed from the freeze-drier the slices of freeze-dried strawberry puree were placed into glass jars containing hot (67° C.) calcium chloride, which was used as a drying agent. The slices were separated from the drying agent by means of pieces of porous paper. The glass jars were sealed immediately, and the samples were kept in this way until the various tests were performed.

VI. TESTS PERFORMED ON THE FREEZE-DRIED PUREE SLICES

Four different objective or mechanical tests were performed on all of the freeze-dried strawberry puree slices. A panel evaluation of texture was carried out for all slices, and a panel ranking for flavor, color, and texture was performed for the best five treatments plus the standard used in the texture test.

Control Strawberries

The standard or control was freeze-dried strawberry slices furnished by the Post Division of General Foods, Battle Creek, Michigan. The berries were thought to have been produced in Oregon. Variety and other items of information concerning the history of the strawberries could not be determined.

Spread Test

This test was used to measure the increase in diameter of the slices during a one-min. rehydration period. One freeze-dried slice from each replicate of each treatment was used. The slice was placed in the trough of a Bostwick Consistometer made by Central Scientific Co., Chicago. The instrument was leveled before being used. This instrument was used because it was hoped that the slight incline in the trough would provide a small impetus which would make differences in tendency to disintegrate on rehydration more pronounced and easily detected and because this instrument could be used for all samples as a common factor in the testing of the tendency to disintegrate.

The greatest diameter of the dry slice was measured by means of a drafting divider and a ruler. The sample was then rehydrated; 1 ml. of distilled water was used. After one min. the greatest diameter occupied by the rehydrated puree slice (but not by the rehydrating water alone, if this diameter was greater) was measured as before. Both diameters were measured to the nearest 0.05 mm. The percentage increase in diameter on rehydration was calculated.

Height Test

This test was conducted along with the spread test. The greatest height of the dry slice was measured before rehydration, and the greatest height of the rehydrated slice was measured one min. after the rehydrating water was added. Both heights were measured with an adjustable depth gauge and a ruler; both were measured to the nearest 0.05 mm. The percentage decrease in height one min. after rehydration with 1 ml. of distilled water was calculated.

Shatter Test

For this test a Burrell Wrist Action Shaker (The Burrell Corp., Pittsburgh, Pa.) was used. One dry slice from each replicate of each treatment was subjected to this test. The slice was removed from storage over calcium chloride, weighed to the nearest one thousandth of a gm., and placed in a 125-ml. glass beaker which contained 6 gm. of glass beads (average diameter, 5 mm.). The shaker was adjusted so as to obtain maximum agitation; this meant that any point on the bottom

of the beaker moved 4 in. from side to side during the cycle of agitation. This agitation was carried out for two min. The piece of the slice which had not been disintegrated to powder was then weighed to the nearest one thousandth of a gm., and the percentage of the weight of the slice retained after the shatter test was calculated.

Shear Test

For the shear test the Allo-Kramer Shear Press (Precision Metals Engineering, Inc., Rockville, Md.) was used (94). The 250-lb. ring was employed; the maximum force required to shear the sample was recorded by means of a ring dynamometer and strain gauge. The shear and compression cell was used; two slices of each sample were placed in the center of the cell. Each replicate of each treatment was tested once, with the exception of the first six treatments. In the case of these samples, each replicate of each treatment was tested twice in order to obtain an idea of the variability inherent in the test. The speed control was set such that the descent of the shear bar required 46 sec. The cell was washed with hot water and dried with acetone after each trial.

The maximum force required to shear the sample was recorded in terms of the dial reading. This reading was converted to lbs. of force by the use of the standard curve for the 250-lb. ring.

Texture Panel

A panel of five adults was used. The panel was read the following statement concerning food texture (mainly from the Literature Review):

A consumer awareness study has shown that texture was the most often mentioned of the three food quality attributes (flavor, appearance, and texture). Texture was especially conspicuous in bland foods or in foods designed to be crunchy or crips (192). Matz considered texture to be the second most important food attribute with appearance being first. Generally those foods eaten in largest quantities by all cultures were white in color, soft in texture, and bland in flavor (123). Texture was important in the concepts of desirable maturity in vegetables and ripeness in fruits (96).

"Texture" was derived from the Latin verb "to weave" and was probably first applied in the English language with reference to fabrics (123). Webster's dictionary defined texture as "the disposition or manner of union of the particles of a body or substance" (96).

Texture was the least well described food quality attribute, probably because of the lack of a bridge between theoretical and practical rheology and because of the restricted nature of most texture work (193). Texture has been defined in terms of hardness or softness of kernels, rigidity of solid units, consistency or "body," toughness, stringiness, slicing quality, crispness, visual appearance of the fineness of grain, and mouth feeling of fineness of grain. All of these definitions have referred to specific food products (193). A committee of the Institute of Food Technologists (1959) defined texture as "those properties apprehended by the eyes and by the skin and muscles of the mouth" (123). Kramer defined texture as those sensations perceived by the sense of feel only and as that part of rheology

dealing with the deformation of matter by forces greater than gravity (96). Under this definition the sense organs that perceived texture were: (1) receptors in the hard and soft palate, tongue, and gums (smoothness, roughness, stickiness, and slickness); (2) receptors in the roots of the teeth (elasticity and brittleness); and (3) receptors in the muscles and tendons of mastication (elasticity, brittleness, and viscosity) (123).

A classification based on the deformation and flow of matter as perceived by sight and as caused by forces greater than 1.0 gravity was one way of subdividing textural characteristics (96). This is the system of classification of textural characteristics to be used in this panel.

The panel was also told to consider the texture evaluation for these purposes to be composed of two factors: brittleness when dry, 20 per cent (as sensed by handling); and disintegration in water, 80 per cent (as sensed by mouth feel).

The only light in the blacked-out room came from fluorescent lamps with daylight bulbs covered by red cellophane. Each panelist had one of these lights.

Each replicate of each treatment was tested once. In order to separate the three replicates of each treatment, the samples were tasted in the following order: all of replicate one, all of replicate two, and then all of replicate three. Increasing order by treatment number was used within all replicates.

A seven point hedonic scale was employed. Natural freeze-dried strawberry slices, previously described under "Control Strawberries," were used as the standard.

Ten samples were done at each sitting. All ten were placed in desiccators (one for each panelist) immediately before the panel sitting was conducted. A standard was tested before each set of ten samples.

The same system for judging was followed throughout all of the texture panel work. A sample was moistened with 1 ml. of distilled water; the sample was held in a small spoon. All judges moistened their own samples simultaneously. After one min. the judges were told to taste the sample, judge its texture (in terms of mouth feel) as compared to that of the standard, and record their opinions.

Opinions of the judges were evaluated in terms of a numbering system going from seven ("like very much better than standard") to one ("dislike very much more than standard"). Each judge's score for each sample was recorded, as well as total panel score for the sample. Total panel scores for the three replicates of each treatment were added to give a total score for each treatment.

Ranking Panel Test

The top five treatments on the basis of total treatment score plus the standard were presented to the panel for ranking. Three slices of each treatment were presented, one from each replicate.

This panel test was conducted using fluorescent lamps with daylight bulbs. Color was judged in the dry condition, and texture and flavor were evaluated after a one-min. rehydration period. Six was designated as the lowest position (worst), and one was designated as the highest position (best).

VII. STATISTICAL ANALYSIS

The following effects were tested by means of the analysis of variance:

1. Effect of amount and type of sugar
2. Effect of method of blending
3. Effect of method of freezing of the strawberries used
4. Effect of amount of water
5. Effect of various colloidal stabilizers and levels of same
6. Effect of deaeration immediately following the blending process
7. Effect of temperature of the water used in blending.

Each effect was analyzed on the basis of panel scores, spread test, shear test, height test, and shatter test. There were thirty-five different analyses of variance. The ANOVAR subroutine (21) on the IBM Model 7040 digital computer (The University of Tennessee Computing Center) was used to perform the analysis of variance calculations.

Duncan's multiple range test subroutine (146) on the IBM Model 1460 digital computer (The University of Tennessee Computing Center) was used to perform this test at the 0.05 level of probability. With the exception of certain groups of means in effect five the test was done for all sources of variation which were included in the analysis of variance models and which were found to have an F test significant at the 0.05 level. Within the analysis for effect five the least significant difference (L. S. D.) for significance at the 0.05 level (179) is given for differences between treatments as shown by panel scores, by shear test values, by shatter test values, by spread test values, and by height test values. This was done because of the problems involved in the tabular presentation of the results of such a large Duncan's multiple range test. With these data similar conclusions would probably result from either test.

The BMDO2R subroutine (70) on the IBM Model 7040 computer was used for the stepwise multiple regression analysis. The ability of shear test, shatter test, spread test, and height test to predict total panel score for a replicate of a certain treatment was tested. A prediction equation was constructed as a result of the analysis. Each replicate of each treatment was used separately.

CHAPTER IV

RESULTS AND DISCUSSION

I. EFFECT OF AMOUNT AND TYPE OF SUGAR

Results of the analysis of variance to determine the effect of amount and type of sugar as measured by panel test are shown in Table I, and results of the analysis of variance for shear, shatter, spread, and height tests are given in Table II. The composition and meaning of the means for the five types of tests are given in Table III. Results of Duncan's multiple range test for treatment and differences as measured by all five tests are given in Table IV, and Table V contains the results of Duncan's multiple range test (Duncan's) for differences between replicates in the panel test. Duncan's and the L. S. D. were used only in cases where the F test was significant at the 0.05 level of probability. This statement applies to the tests for all seven effects.

Both treatment differences and replicate differences were significant at the 0.05 level in the panel test (Table I). Only treatment differences were significant at this level in the shear, shatter, spread, and height tests (Table II).

Duncan's showed that the following treatments were not significantly different from the control (natural freeze-dried strawberry slices) at the 0.05 level: no sugar; sucrose, 20 gm., and sucrose, 40 gm. All other treatments were significantly poorer from the

TABLE I

SUMMARY OF THE ANALYSIS OF VARIANCE FOR THE EFFECT OF AMOUNT AND TYPE OF SUGAR ON THE TEXTURE OF FREEZE-DRIED FORMULATED STRAWBERRY SLICES AS MEASURED BY PANEL TEST

Source	d. f.	Mean Squares
Treatments	11	7.4965*
Replicates	2	5.2056*
Error	166	1.4987

*Statistical significance at the 0.05 level of probability.

TABLE II

SUMMARY OF THE ANALYSIS OF VARIANCE FOR THE EFFECT OF AMOUNT AND TYPE OF SUGAR ON THE TEXTURE OF FREEZE-DRIED FORMULATED STRAWBERRY SLICES AS MEASURED BY SHEAR, SHATTER, SPREAD, AND HEIGHT TESTS

		Mean Squares			
Source	d. f.	Shear Test	Shatter Test	Spread Test	Height Test
Treatments	11	117.19 *	1011.60 *	666.37 *	553.68 *
Replicates	2	2.76	101.11	476.09	196.42
Error	22	39.97	140.44	180.38	86.73

*Statistical significance at the 0.05 level of probability.

TABLE III

COMPOSITION AND EXPLANATION OF TEST MEANS IN TESTS FOR TEXTURE OF FREEZE-DRIED FORMULATED STRAWBERRY SLICES

Mean	Composition	Explanation
Panel	Five judges by three replicates (in the case of treatment differences) or the number of treatments shown (in the case or replicate differences).	Panel scores on a seven point hedonic scale.
Shear	Three replicates.	Pounds of force required to shear (as measured by Kramer Shear Press).
Shatter	Three replicates.	Per cent of weight remaining after shatter test.
Spread	Three replicates.	Per cent increase in diameter during rehydration (one minute).
Height	Three replicates.	Per cent decrease in height during rehydration (one minute).

TABLE IV

RESULTS OF DUNCAN'S MULTIPLE RANGE TEST FOR THE EFFECT OF AMOUNT AND TYPE OF SUGAR ON THE TEXTURE OF FREEZE-DRIED FORMULATED STRAWBERRY SLICES AS MEASURED BY SHEAR, SHATTER, SPREAD, HEIGHT AND PANEL TESTS[1]

	Means for Tests				
Treatment[2]	Panel[3]	Shear[3]	Shatter[3]	Spread[3]	Height[3]
NS	3.93 a	12.33 abc	88.57 ab	2.23 cd	20.83 de
S, 5 gm.	2.13 c	9.77 bc	67.00 bc	53.60 a	49.77 a
S, 10 gm.	2.20 c	6.83 bc	60.03 cd	36.67 ab	45.97 ab
S, 20 gm.	3.73 ab	10.10 bc	91.13 a	14.60 bcd	22.23 cde
S, 30 gm.	2.87 bc	11.93 bc	94.27 a	15.43 bcd	53.20 ab
S, 40 gm.	3.07 abc	24.63 a	97.87 a	27.53 abc	45.20 a
CS, 5 gm.	2.47 c	4.17 c	61.67 cd	16.23 bcd	15.83 e
CS, 10 gm.	2.40 c	5.57 bc	75.60 abc	12.63 bcd	40.10 abc
CS, 20 gm.	2.07 c	3.57 c	42.70 d	30.70 ab	40.70 ab
CS, 30 gm.	2.33 c	15.70 abc	59.03 cd	19.93 bcd	36.17 abcd
CS, 40 gm.	2.73 bc	15.87 abc	94.97 a	14.30 bcd	19.30 e
Control	4.00 a	17.90 ab	90.97 a	0.00 d	28.57 bcde

[1]Within each column means followed by the same letter are not significantly different at the 0.05 level of probability.

[2]Amounts are based on the standard size batch. Symbols have the following meanings: NS, no sugar; S, sucrose; CS, corn sirup; Control, control strawberries.

[3]See Table III, page 63.

TABLE V

RESULTS OF DUNCAN'S MULTIPLE RANGE TEST FOR DIFFERENCE BETWEEN REPLICATES IN PANEL TEST FOR THE EFFECT OF AMOUNT AND TYPE OF SUGAR ON THE TEXTURE OF FREEZE-DRIED FORMULATED STRAWBERRY SLICES[1]

Replicate	Mean[2]
1	2.68 b
2	3.17 a
3	2.63 b

[1]Means followed by the same letter are not significantly different at the 0.05 level of probability.

[2]See Table III, page 63.

standpoint of texture than the control. These results are presented in Table IV, along with the results for the other four texture tests.

The shear test showed the following treatments to be significantly poorer than the control: corn sirup, 5 gm.; and corn sirup, 20 gm. (significance in the entire study refers to the 0.05 level of probability). All other treatments were not significantly different from the control.

In the shatter test the following treatments appeared not to be significantly different from the control: no sugar; sucrose, 20 gm.; sucrose, 30 gm.; sucrose, 40 gm.; corn sirup, 10 gm.; and corn sirup, 40 gm. Other treatments were significantly poorer than the control.

In the spread test the following treatments were not significantly different from the control: sucrose, 5 gm.; sucrose, 10 gm.; sucrose, 40 gm.; and corn sirup, 20 gm. Other treatments were significantly poorer than the control. In the height test only two levels of sucrose (5 gm. and 40 gm.) were significantly poorer than the control.

In general, sucrose appeared to be slightly better from the standpoint of texture than corn sirup. The texture for samples containing no sugar was very good in all tests. Texture appeared to improve as sugar level increased within either of the two sugar categories. This was contrary to the results of a preliminary study. Possibly some degree of polymerization with the colloidal additive or with compounds present in the fruit was responsible for this finding.

These results agreed with the work of Dawson (41). However, they disagreed with the work of Bartlett and Hard (15) and that of Talburt et al. (198).

The second replicate was significantly different from the first and third replicates on the basis of panel test (Table V, page 65). Since this finding was observed only in the panel test and not in the objective tests, it could probably be concluded that some difference in the conditions prevailing during the panel tests of the different replicates accounted for the significant difference between replicates. Position with respect to the heat source during freeze-drying could have been important. Replicate one was always nearest the shelf, with two above it and three on top. Probably this did not occur, because a significant difference between replicates was found in only one other case, panel test for effect of freezing method. In this case, the first replicate was significantly different from the second and third replicates. Position with respect to the shelf during freeze-drying was probably not important, and chance or technique in conducting the taste panel probably contributed to the significant differences between replicates where such a difference was observed.

II. EFFECT OF BLENDING METHOD

The summary for the analysis of variance for the effect of blending method as measured by panel test is contained in Table VI, while the summary for this effect as measured by shear, shatter,

TABLE VI

SUMMARY OF THE ANALYSIS OF VARIANCE FOR THE EFFECT OF BLENDING METHOD ON THE TEXTURE OF FREEZE-DRIED FORMULATED STRAWBERRY SLICES AS MEASURED BY PANEL TEST

Source	d. f.	Mean Squares
Treatments	2	8.29*
Replicates	2	3.29
Error	40	1.85

*Statistical significance at the 0.05 level of probability.

spread, and height tests is given in Table VII. Treatment differences were found to be significant in the panel, shatter, and height tests. The results for Duncan's multiple range test on the means involved in these three tests are given in Table VIII. In all three tests dispersion of the colloidal stabilizer by stirring into 95 per cent ethanol caused texture to be significantly poorer than the texture of the control and the texture of formulated slices prepared by sifting the stabilizer into the vortex of the blending water. The effect of ethanol rather than the blending method may be important in this case.

Possibly these results could be explained by the findings of Blake (19). He found that glycols, acetone, and alcohols could be used to dissolve ice from frozen tissue. Since the strawberry tissue was only partly thawed when used, this explanation for the effect on texture caused by blending method may be valid.

III. EFFECT OF FREEZING METHOD

The effect of the method used for freezing the strawberries was the subject of this portion of the study. The effect of the method of freezing the ropes of puree was not investigated.

The summary of the analysis of variance for the panel test is given in Table IX. The summary for the shear, shatter, spread, and height tests is given in Table X. Treatment differences were significant in the panel, shatter, and height tests; Duncan's multiple range test for the means involved in these three tests is presented in

TABLE VII

SUMMARY OF THE ANALYSIS OF VARIANCE FOR THE EFFECT OF BLENDING METHOD ON THE TEXTURE OF FREEZE-DRIED FORMULATED STRAWBERRY SLICES AS MEASURED BY SHEAR, SHATTER, SPREAD, AND HEIGHT TESTS

		Mean Squares			
Source	d. f.	Shear Test	Shatter Test	Spread Test	Height Test
Treatments	2	57.88	162.58 *	432.12	336.33 *
Replicates	2	22.06	110.41	101.44	222.76
Error	4	13.89	21.14	108.85	34.51

*Statistical significance at the 0.05 level of probability.

TABLE VIII

RESULTS OF DUNCAN'S MULTIPLE RANGE TEST FOR THE EFFECT OF BLENDING METHOD ON THE TEXTURE OF FREEZE-DRIED FORMULATED STRAWBERRY SLICES AS MEASURED BY PANEL TEST, SHATTER TEST, AND HEIGHT TEST[1]

	Means for Tests		
Treatment	Panel[2]	Shatter[2]	Height[2]
Sift into vortex of water	3.73 a	91.13 a	22.23 b
Stir into 95 per cent ethanol	2.60 b	78.30 b	42.90 a
Control strawberries	4.00 a	90.97 a	28.57 b

[1]Within each column means followed by the same letter are not significantly different at the 0.05 level of probability.

[2]See Table III, page 63.

TABLE IX

SUMMARY OF THE ANALYSIS OF VARIANCE FOR THE EFFECT OF FREEZING METHOD ON THE TEXTURE OF FREEZE-DRIED FORMULATED STRAWBERRY SLICES AS MEASURED BY PANEL TEST

Source	d. f.	Mean Squares
Treatments	3	7.31*
Replicates	2	4.02*
Error	54	1.18

*Statistical significance at the 0.05 level of probability.

TABLE X

SUMMARY OF THE ANALYSIS OF VARIANCE FOR THE EFFECT OF FREEZING METHOD ON THE TEXTURE OF FREEZE-DRIED FORMULATED STRAWBERRY SLICES AS MEASURED BY SHEAR, SHATTER, SPREAD, AND HEIGHT TESTS

		Mean Squares			
Source	d. f.	Shear Test	Shatter Test	Spread Test	Height Test
Treatments	3	62.31	307.31 *	322.40	224.99 *
Replicates	2	13.72	29.48	20.75	34.14
Error	6	28.01	58.40	101.43	12.92

*Statistical significance at the 0.05 level of probability.

Table XI. Replicate differences were significant in the panel test; Duncan's for these means is given in Table XII.

Duncan's for panel, shatter, and height tests showed that air blast freezing (-29° C.), liquid nitrogen freezing (-196° C.), and Freon Twelve freezing (-30° C.) were not significantly different in their effect on texture. However, formulated freeze-dried strawberry slices prepared from strawberries frozen in each of the three ways had significantly poorer texture than the control.

These results agreed with the work of Lee et al. (103), Marion and Stadelman (121), Barrie (13), Leader (101), and Samygin and Matveeva (150). A variety of tissues, both plant and animal, was employed in these studies. The results disagreed with the work of Asahina (6) and that of Deatherage and Hamm (42).

The difference between replicates in the panel test is discussed under section I of this chapter. The discussion is found on page 67.

IV. EFFECT OF AMOUNT OF BLENDING WATER

The summary of the analysis of variance for the effect of the amount of blending water as measured by panel test is given in Table XIII. The summary for shear, shatter, spread, and height tests is presented in Table XIV. Treatment differences were significant in the panel and height tests. Duncan's multiple range test for these differences is shown in Table XV.

Duncan's for the panel test showed that the control and the formulated slices in which the amount of blending water was 200 ml.

TABLE XI

RESULTS OF DUNCAN'S MULTIPLE RANGE TEST FOR THE EFFECT OF METHOD OF FREEZING ON THE TEXTURE OF FREEZE-DRIED FORMULATED STRAWBERRY SLICES AS MEASURED BY PANEL TEST, SHATTER TEST, AND HEIGHT TEST[1]

Treatment	Means for Tests		
	Panel[2]	Shatter[2]	Height[2]
Air blast (-29° C.)	2.73 b	69.03 b	41.70 a
Liquid nitrogen (-196° C.)	2.67 b	72.03 b	46.13 a
Freon Twelve (-30° C.)	2.47 b	71.63 b	47.60 a
Control strawberries	4.00 a	90.97 a	28.57 b

[1]Within each column means followed by the same letter are not significantly different at the 0.05 level of probability.

[2]See Table III, page 63.

TABLE XII

RESULTS OF DUNCAN'S MULTIPLE RANGE TEST FOR DIFFERENCE BETWEEN REPLICATES IN PANEL TEST FOR EFFECT OF METHOD OF FREEZING ON TEXTURE OF FREEZE-DRIED FORMULATED STRAWBERRY SLICES[1]

Replicate	Mean[2]
1	2.45 b
2	3.25 a
3	3.20 a

[1]Means followed by the same letter are not significantly different at the 0.05 level of probability.

[2]See Table III, page 63.

TABLE XIII

SUMMARY OF THE ANALYSIS OF VARIANCE FOR THE EFFECT OF AMOUNT OF BLENDING WATER ON THE TEXTURE OF FREEZE-DRIED FORMULATED STRAWBERRY SLICES AS MEASURED BY PANEL TEST

Source	d. f.	Mean Squares
Treatments	2	10.07*
Replicates	2	3.47
Error	40	1.29

*Statistical significance at the 0.05 level of probability.

TABLE XIV

SUMMARY OF THE ANALYSIS OF VARIANCE FOR THE EFFECT OF AMOUNT OF BLENDING WATER ON THE TEXTURE OF FREEZE-DRIED FORMULATED STRAWBERRY SLICES AS MEASURED BY SHEAR, SHATTER, SPREAD, AND HEIGHT TESTS

		Mean Squares			
Source	d. f.	Shear Test	Shatter Test	Spread Test	Height Test
Treatments	2	54.04	394.04	453.42	556.02 *
Replicates	2	14.17	21.64	288.61	320.36
Error	4	13.51	98.88	78.84	63.79

*Statistical significance at the 0.05 level of probability.

TABLE XV

RESULTS OF DUNCAN'S MULTIPLE RANGE TEST FOR THE EFFECT OF AMOUNT OF BLENDING WATER ON THE TEXTURE OF FREEZE-DRIED FORMULATED STRAWBERRY SLICES AS MEASURED BY PANEL AND HEIGHT TESTS[1]

Treatment[2]	Test Means	
	Panel[3]	Height[3]
100 ml.	2.47 b	48.33 a
200 ml.	3.73 a	22.23 c
Control	4.00 a	28.57 b

[1]Within each column means followed by the same letter are not significantly different at the 0.05 level of probability.

[2]Amounts are based on the standard size batch. Amounts refer to the number of ml. of blending water used.

[3]See Table III, page 63.

(in the standard size batch) were not significantly different. The formulated product in which the amount of blending water used was 100 ml. was shown to have a significantly poorer texture than the other two treatments.

Duncan's for the height test showed all three treatments to be significantly different. The treatments ranked as follows (with the best texture first and the poorest last): 200 ml. of blending water; control; and 100 ml. of blending water.

This effect on texture may have been due to the difficulties inherent in using an amount of blending water which is too small. This caused discontinuities (due to poor mixing) which would have been noticeable to panel members and which would be susceptible to collapse upon rehydration (as measured by the height test). Preliminary studies indicated that 100 ml. of blending water in the standard size batch was on the borderline between a sufficient amount of water and an insufficient amount.

These results within the range of amounts of liquid studied disagreed with the results of Hanson (67). He found that texture improved as liquid level decreased in the case of egg- and starch-thickened precooked frozen foods such as white sauces and pudding-type desserts.

V. EFFECT OF KIND AND AMOUNT OF STABILIZER

The summary of the analysis of variance for the effect of kind and amount of stabilizer as measured by panel test is presented in

Table XVI. The summary for shear, shatter, spread, and height tests is given in Table XVII. Treatment differences were significant for panel, shear, shatter, spread, and height tests; the L. S. D. tests for these differences are presented in Table XIX. Descriptions of the treatments corresponding to the treatment numbers used in this part of the study are presented in Table XVIII.

On the basis of panel score the following treatments were not significantly different from the control (using L. S. D. at the 0.05 level as a test criterion): Hercules CMC, 1.00 gm.; Velatex Gelatin, 4.50 gm.; Pad Guar Gum, 1.00 gm.; and low methoxyl pectin, 1.00 gm. All other treatments had a significantly poorer texture than the control.

On the basis of shear test the following treatments were not significantly different from the control (using L. S. D.): Dupont CMC (P-75-H), 1.00 gm.; Velatex Gelatin, 2.25 gm.; Velatex Gelatin, 4.50 gm.; Pad Guar Gum, 1.00 gm.; Kelgin MV, 1.00 gm.; Kelcoloid HVF, 1.00 gm.; Kelcoloid S, 1.00 gm.; and Kelcoloid LVF, 1.00 gm., sifted. Kelcoloid LVF, 1.00 gm., dispersed in ethanol, had a significantly higher shear value than the control. All other treatments had significantly lower shear values than the control.

The L. S. D. test on the results of the shatter test indicated that the following treatments were not significantly different from the control: Hercules CMC, 1.00 gm.; Dupont CMC (P-75S-H), 1.00 gm.; Dupont CMC (P-75-M), 1.00 gm.; Dupont CMC (P-75-L), 1.00 gm.; Dupont

TABLE XVI

SUMMARY OF THE ANALYSIS OF VARIANCE FOR THE EFFECT OF KIND AND AMOUNT OF STABILIZER ON THE TEXTURE OF FREEZE-DRIED FORMULATED STRAWBERRY SLICES AS MEASURED BY PANEL TEST

Source	d. f.	Mean Squares
Treatments	37	9.51*
Replicates	2	1.94
Error	530	1.13

*Statistical significance at the 0.05 level of probability.

TABLE XVII

SUMMARY OF THE ANALYSIS OF VARIANCE FOR THE EFFECT OF KIND AND AMOUNT OF STABILIZER ON THE TEXTURE OF FREEZE-DRIED FORMULATED STRAWBERRY SLICES AS MEASURED BY SHEAR, SHATTER, SPREAD, AND HEIGHT TESTS

		Mean Squares			
Source	d. f.	Shear Test	Shatter Test	Spread Test	Height Test
Treatments	37	104.86 *	1250.92 *	511.40 *	340.48 *
Replicates	2	19.44	3.51	2.48	35.96
Error	74	12.19	246.39	109.48	87.41

*Statistical significance at the 0.05 level of probability.

TABLE XVIII

TREATMENTS USED IN THE TEST FOR EFFECT OF KIND AND AMOUNT OF STABILIZER ON THE TEXTURE OF FREEZE-DRIED FORMULATED STRAWBERRY SLICES

Treatment No.	Treatment[1]
1	Hercules CMC, 1.00 gm.
2	Dupont CMC (P-75S-H), 1.00 gm.
3	Dupont CMC (P-75-M), 1.00 gm.
4	Dupont CMC (P-75-L), 1.00 gm.
5	Dupont CMC (P-75-H), 1.00 gm.
6	GM 246 (Germantown), 1.00 gm.
7	Velatex Gelatin, 2.25 gm.
8	Velatex Gelatin, 4.50 gm.
9	Velatex Gelatin, 1.00 gm.
10	Pad Guar Gum, 1.00 gm.
11	Meer Guar Gum, 1.00 gm., sift
12	Meer Guar Gum, 1.00 gm., ethanol
13	Meer Guar Gum, 3.00 gm., sift
14	Hydrolyzed Cereal Solids, 1.00 gm.
15	Kelgin MV, 1.00 gm.
16	Kelcoloid HVF, 1.00 gm.
17	Kelcoloid S, 1.00 gm.
18	Kelcoloid LVF, 1.00 gm., sift
19	Kelcoloid LVF, 1.00 gm., ethanol

TABLE XVIII (continued)

Treatment No.	Treatment[1]
20	Kelcoloid LVF, 1.00 gm.; $CaCl_2$, 1.37 gm.
21	Kelcoloid LVF, 1.00 gm.; ascorbic acid, 0.50 gm.
22	OK Dri Sweet Malto Dextrin, 1.00 gm.
23	OK Keojel Starch, 1.00 gm.
24	Snowflake Starch, 1.00 gm.
25	FTD Starch, 1.00 gm.
26	Starvis, 1.00 gm.
27	Supercol GF, 0.25 gm.
28	Supercol GF, 0.40 gm.
29	Supercol F, 0.25 gm.
30	Supercol F, 0.40 gm.
31	LM Pectin, 1.00 gm.; $CaCl_2$, 1.00 gm.
32	LM Pectin, 3.00 gm.; $CaCl_2$, 1.00 gm.
33	LM Pectin, 10.00 gm.; $CaCl_2$, 1.00 gm.
34	LM Pectin, 1.00 gm.
35	Myverol 18-00, 1.00 gm.
36	Myverol 18-07, 1.00 gm.
37	Kraystay Type K, 1.00 gm.
38	Control strawberries

[1]Amounts are based on the standard size batch.

TABLE XIX

EFFECT OF AMOUNT AND TYPE OF STABILIZER ON THE TEXTURE OF FREEZE-DRIED FORMULATED STRAWBERRY SLICES AS MEASURED BY PANEL, SHEAR, SHATTER, SPREAD, AND HEIGHT TESTS

Treatment No.[1]	Test Means				
	Panel[2]	Shear[2]	Shatter[2]	Spread[2]	Height[2]
1	3.73	10.10	91.13	14.60	22.23
2	2.80	9.13	77.90	31.37	31.10
3	2.00	12.07	79.20	25.30	40.57
4	1.47	6.90	68.00	14.33	40.13
5	2.73	13.00	71.10	19.70	34.33
6	1.87	9.17	43.43	27.90	51.27
7	1.47	14.40	82.27	66.50	41.10
8	4.47	22.13	100.00	43.77	9.93
9	2.20	5.83	51.03	0.00	44.70
10	3.73	13.60	88.83	14.17	27.57
11	2.80	6.73	80.13	1.43	37.23
12	2.53	7.80	79.93	26.80	47.23
13	3.07	7.67	90.37	6.87	21.43
14	2.20	6.03	45.50	9.13	38.33
15	2.87	14.63	83.53	3.33	31.33
16	2.93	14.83	96.30	24.93	27.50
17	2.93	13.87	81.07	19.83	28.97
18	2.47	22.00	98.67	26.17	31.73
19	2.80	32.27	87.83	7.57	34.10
20	2.00	4.80	39.57	8.00	39.93

TABLE XIX (continued)

Treatment No.[1]	Test Means				
	Panel[2]	Shear[2]	Shatter[2]	Spread[2]	Height[2]
21	2.07	8.67	82.83	22.30	34.20
22	1.67	4.60	29.67	11.40	50.00
23	1.40	5.33	45.77	11.30	50.83
24	1.67	7.07	47.13	19.13	47.43
25	1.27	5.17	42.20	18.90	55.40
26	1.47	6.23	51.40	13.77	45.40
27	1.87	5.47	59.17	16.57	50.13
28	2.27	8.07	63.10	23.63	52.53
29	2.13	6.45	59.30	17.90	48.73
30	2.87	7.47	76.50	13.53	48.40
31	1.40	6.17	44.90	24.07	44.17
32	1.53	4.73	37.17	5.93	44.67
33	2.47	7.50	36.27	5.33	40.00
34	3.27	10.57	87.10	3.10	27.77
35	1.60	5.50	59.07	33.47	58.30
36	1.60	4.43	56.50	7.67	36.33
37	2.73	7.90	65.83	7.10	36.33
38	4.00	17.90	90.97	0.00	28.57
L. S. D.[3]	0.74	5.67	25.48	16.99	15.18

[1]See Table XVIII, page 84.

[2]See Table III, page 63.

[3]L. S. D. value for treatment differences at the 0.05 level of significance.

CMC (P-75-H), 1.00 gm.; Velatex Gelatin, 2.25 gm.; Velatex Gelatin, 4.50 gm.; Pad Guar Gum, 1.00 gm.; Meer Guar Gum, 1.00 gm., sifted; Meer Guar Gum, 1.00 gm., dispersed in ethanol; Meer Guar Gum, 3.00 gm., sifted; Kelgin MV, 1.00 gm.; Kelcoloid HVF, 1.00 gm.; Kelcoloid S, 1.00 gm.; Kelcoloid LVF, 1.00 gm., sifted; Kelcoloid LVF, 1.00 gm., dispersed in ethanol; Kelcoloid LVF, 1.00 gm., with 0.50 gm. of ascorbic acid added; Supercol F, 0.40 gm.; low methoxyl pectin, 1.00 gm.; and Kraystay Type K, 1.00 gm. All other treatments had a significantly poorer texture than the control.

On the basis of the spread test the following treatments were not significantly different from the control (based on the L. S. D. test): Hercules CMC, 1.00 gm.; Dupont CMC (P-75-L), 1.00 gm.; Velatex Gelatin, 1.00 gm.; Pad Guar Gum, 1.00 gm.; Meer Guar Gum, 1.00 gm., sifted; Meer Guar Gum, 3.00 gm., sifted; Hydrolyzed Cereal Solids, 1.00 gm.; Kelgin MV, 1.00 gm.; Kelcoloid LVF, 1.00 gm., dispersed in ethanol; Kelcoloid LVF, 1.00 gm., with 1.37 gm. of calcium chloride added; OK Dri Sweet Malto Dextrin, 1.00 gm.; OK Keojel Starch, 1.00 gm.; Starvis, 1.00 gm.; Supercol GF, 0.25 gm.; Supercol F, 0.40 gm.; low methoxyl pectin, 3.00 gm., with 1.00 gm. of calcium chloride added; low methoxyl pectin, 10.00 gm., with 1.00 gm. of calcium chloride added; Myverol 18-07, 1.00 gm.; and Kraystay Type K, 1.00 gm. All other treatments exhibited a texture which was significantly poorer than that of the control.

Based on the height test the following treatments were not significantly different from the control (using L. S. D. at the 0.05 level

as the test criterion): GM 246 (Germantown), 1.00 gm.; Velatex Gelatin, 1.00 gm.; Meer Guar Gum, 1.00 gm., dispersed in ethanol; OK Dri Sweet Malto Dextrin, 1.00 gm.; OK Keojel Starch, 1.00 gm.; Snowflake Starch, 1.00 gm.; FTD Starch, 1.00 gm.; Starvis, 1.00 gm.; Supercol GF, 0.25 gm.; Supercol GF, 0.40 gm.; Supercol F, 0.25 gm.; Supercol F, 0.40 gm.; low methoxyl pectin, 1.00 gm., with 1.00 gm. of calcium chloride; low methoxyl pectin, 3.00 gm., with 1.00 gm. of calcium chloride; Myverol 18-00, 1.00 gm.; and Myverol 18-07, 1.00 gm. All other treatments were shown to have a significantly poorer texture than the control.

Based on the criterion of significant superiority over the control (by L. S. D. at the 0.05 level) or lack of significant difference from the control (by L. S. D. at the 0.05 level) or a combination of the two for three or more tests, seven treatments were considered to have promise. The seven were as follows: Hercules CMC, 1.00 gm.; Velatex Gelatin, 4.50 gm.; Pad Guar Gum, 1.00 gm.; Kelgin MV, 1.00 gm.; Kelcoloid LVF, 1.00 gm., dispersed in ethanol; Supercol F, 0.40 gm.; and low methoxyl pectin, 1.00 gm. (with no calcium chloride added).

These results agreed with the work of Wegener *et al.* (213), Murphy *et al.* (137), Hanson *et al.* (67), Miers (131), and Swenson (188). The effect of added calcium ions did not correspond to that found by Collins and Wiley in the case of thermal-processed apple slices (31). The effect of the colloidal stabilizers may have been due to their influence on the viscosity of the rehydrated strawberry

slices. This effect was cited in several publications by manufacturers of stabilizers (49,72,73,88,93,126,127).

VI. EFFECT OF DEAERATION

The summary of the analysis of variance for the effect of deaeration as measured by panel test is shown in Table XX. The summary for the shear, shatter, spread, and height tests is given in Table XXI. Treatment differences were significant only in the panel test. Duncan's multiple range test for these differences is given in Table XXII. Deaeration refers to the removal of air from the pureed sample before pouring it into the wiener casing.

The deaerated sample and the control were not significantly different, but both were significantly better from the standpoint of texture than the sample which had not been deaerated. A probable explanation would be that deaeration decreases the porosity of the formulated freeze-dried product, making it more dense and less fragile. This would decrease the tendency to shatter in the dry condition and the tendency to become flaccid during rehydration. No report of pertinent work was found in the literature.

VII. EFFECT OF TEMPERATURE OF BLENDING WATER

The summary of the analysis of variance for the effect of blending water temperature as measured by panel test is presented in Table XXIII. The summary for the shear, shatter, spread, and height tests

TABLE XX

SUMMARY OF THE ANALYSIS OF VARIANCE FOR THE EFFECT OF DEAERATION ON THE TEXTURE OF FREEZE-DRIED FORMULATED STRAWBERRY SLICES AS MEASURED BY PANEL TEST

Source	d. f.	Mean Squares
Treatments	2	7.27*
Replicates	2	0.87
Error	40	1.79

*Statistical significance at the 0.05 level of probability.

TABLE XXI

SUMMARY OF THE ANALYSIS OF VARIANCE FOR THE EFFECT OF DEAERATION ON THE TEXTURE OF FREEZE-DRIED FORMULATED STRAWBERRY SLICES AS MEASURED BY SHEAR, SHATTER, SPREAD, AND HEIGHT TESTS

		Mean Squares			
Source	d. f.	Shear Test	Shatter Test	Spread Test	Height Test
Treatments	2	397.26	11.59	187.54	616.21
Replicates	2	171.37	1.00	79.74	366.59
Error	4	267.10	9.11	56.50	261.09

TABLE XXII

RESULTS OF DUNCAN'S MULTIPLE RANGE TEST FOR THE EFFECT OF DEAERATION ON THE TEXTURE OF FREEZE-DRIED FORMULATED STRAWBERRY SLICES AS MEASURED BY PANEL TEST[1]

Treatment	Panel Test Mean[2]
Not Deaerated	2.87 b
Deaerated	4.13 a
Control	4.00 a

[1]Means followed by the same letter are not significantly different at the 0.05 level of significance.

[2]See Table III, page 63.

TABLE XXIII

SUMMARY OF THE ANALYSIS OF VARIANCE FOR THE EFFECT OF TEMPERATURE OF BLENDING WATER ON THE TEXTURE OF FREEZE-DRIED FORMULATED STRAWBERRY SLICES AS MEASURED BY PANEL TEST

Source	d. f.	Mean Squares
Treatments	2	4.02
Replicates	2	4.42
Error	40	1.80

is given in Table XXIV. Treatment differences were significant only in the height test. Duncan's multiple range test for these differences is given in Table XXV.

The samples prepared by using blending water at 30° C. were not significantly different from the control; both the control and the 30° C. sample were significantly better than the sample prepared with blending water at 100° C. This difference was probably due to the fact that hot water would injure the texture of the strawberries and would affect the ability of the stabilizer to alter the texture.

No report of work pertinent to this effect was found in the literature. However, a report applicable to the results of the study as a whole was found. The results generally disagreed with the statement made by Miller and May (132) concerning the effect of freeze-drying on tenderness. They stated that freeze-dried tissue was generally less tender than non-freeze-dried tissue. However, the blending process used in this study and the fact that Miller and May studied the tissue of chicken rather than plant tissue must be taken into account in evaluating this study in the light of their work.

VIII. MULTIPLE REGRESSION ANALYSIS

Results of the multiple regression analysis using the values for the objective tests (shear, shatter, spread, and height tests) as predictors of the panel test score are given in Table XXVI. The order of entry of the independent variables into the prediction equation was

TABLE XXIV

SUMMARY OF THE ANALYSIS OF VARIANCE FOR THE EFFECT OF TEMPERATURE OF BLENDING WATER ON THE TEXTURE OF FREEZE-DRIED FORMULATED STRAWBERRY SLICES AS MEASURED BY SHEAR, SHATTER, SPREAD, AND HEIGHT TESTS

		Mean Squares			
Source	d. f.	Shear Test	Shatter Test	Spread Test	Height Test
Treatments	2	75.88	68.64	162.32	443.53 *
Replicates	2	9.01	92.93	74.63	140.70
Error	4	14.77	54.78	109.92	39.74

*Statistical significance at the 0.05 level of probability.

TABLE XXV

RESULTS OF DUNCAN'S MULTIPLE RANGE TEST FOR THE EFFECT OF BLENDING WATER TEMPERATURE ON THE TEXTURE OF FREEZE-DRIED FORMULATED STRAWBERRY SLICES AS MEASURED BY HEIGHT TEST[1]

Treatment[2]	Height Test Mean[3]
30° C.	22.23 b
100° C.	45.73 a
Control	28.57 b

[1]Means followed by the same letter are not significantly different at the 0.05 level of probability.

[2]Temperatures refer to temperature of blending water.

[3]See Table III, page 63.

TABLE XXVI

RESULTS OF MULTIPLE REGRESSION ANALYSIS USING SHEAR, SHATTER, SPREAD, AND HEIGHT TEST SCORES AS PREDICTORS OF PANEL SCORE FOR TEXTURE OF FREEZE-DRIED FORMULATED STRAWBERRY SLICES[1]

Step Number	Independent Variable	Multiple R	Standard Error of Estimate
1	Shatter	0.57	3.48
2	Height	0.64	3.24
3	Shear	0.67	3.16
4	Spread	0.68	3.13

[1]The F level inclusion was 0.01; the F level for deletion was 0.005; the tolerance level was 0.001.

as follows: shatter, height, shear, and spread. Variables were entered in decreasing order of their power as predictors of the dependent variable. The final value for the multiple R was 0.68 after all independent variables had been entered. Shatter and height test scores were fairly good predictors of panel score. Shear value added 0.03 to multiple R, and spread value added 0.01.

IX. RESULTS OF PANEL RANKING TEST

Results of the panel ranking test for color, flavor, and texture of the six top treatments from the texture panel are presented in Table XXVII. Scores ranged from one (best) to six (worst) within each of the three quality attributes. Using total score within an attribute as a criterion for placing the treatments, a ranking within each attribute could be constructed. The treatments ranked as follows: Velatex Gelatin (4.50 gm., with 20 gm. of sucrose), third in color, second in flavor, and fourth in texture (tie); Pad Guar (1.00 gm., with 20 gm. of sucrose), sixth in color, third in flavor, and fourth in texture (tie); Hercules CMC (1.00 gm., with no sugar), second in color, sixth in flavor, and second in texture (tie); Hercules CMC (1.00 gm., with 20 gm. of sugar), fifth in color, third in flavor (tie), and second in texture (tie); Hercules CMC (1.00 gm., with 20 gm. of sucrose, edible casing), fourth in color, first in flavor, and sixth in texture; control, first in color, third in flavor (tie), and first in texture.

Using the ranking for all three attributes, the overall ranking could be determined. This ranking was as follows: control, first;

TABLE XXVII

RESULTS OF PANEL RANKING TEST FOR COLOR, FLAVOR, AND TEXTURE OF THE SIX BEST TREATMENTS FROM TEXTURE PANEL TEST FOR FREEZE-DRIED FORMULATED STRAWBERRY SLICES[1]

Treatment[2]	Judge 1			Judge 2			Judge 3			Judge 4			Judge 5		
	C	F	T	C	F	T	C	F	T	C	F	T	C	F	T
Velatex Gelatin, 4.5 gm., 20 gm. sucrose	6	2	5	2	5	4	2	2	5	3	4	4	6	2	1
Pad Guar Gum, 1.0 gm., 20 gm. sucrose	4	3	4	5	6	5	6	6	6	4	3	1	5	1	3
Hercules CMC, 1.0 gm., no sugar	1	5	3	3	2	6	3	4	2	2	6	2	2	4	4
Hercules CMC, 1.0 gm., 20 gm. sucrose	3	6	1	4	1	1	5	5	4	6	2	6	3	5	5
Hercules CMC, 1.0 gm., 20 gm. sucrose, edible casing	5	4	6	6	3	3	4	1	3	1	1	5	4	3	6
Control	2	1	2	1	4	2	1	3	1	5	5	3	1	6	2

[1]Color is designated by C, flavor by F, and texture by T. A score of one means "best" and six means "worst" within a quality attribute.

[2]Amounts are based on the standard size batch.

Velatex Gelatin (4.50 gm., with 20 gm. of sucrose), second; Hercules CMC (1.00 gm., with no sucrose) and Hercules CMC (1.00 gm., with 20 gm. of sucrose), tie for third; Hercules CMC (1.00 gm. with 20 gm. of sucrose, edible casing), fifth; and Pad Guar gum (1.00 gm., with 20 gm. of sucrose), sixth.

X. ANALYSIS OF VARIANCE FOR SHEAR PRESS DUPLICATES

The summary of the analysis of variance for shear press duplicates of six treatments is presented in Table XXVIII. The treatment differences were significant at the 0.05 level, but the replicate differences and the duplicate differences were not significant at this level. This finding would tend to substantiate the theory that the variability in shear press values within a replicate of a treatment was not large enough to be of concern in this study and that the variability inherent in the test was small.

XI. ORIGINAL DATA

The original data for each of the seven effects tested in the study are presented in the Appendix in Tables XXIX through XLII, pages 126-146. For each effect panel scores (by individual judges) are presented in one table, and scores for shear, shatter, spread, and height tests are given in a second table. The original data for the variability of shear press duplicates are presented in Table XLIII, page 147.

TABLE XXVIII

SUMMARY OF THE ANALYSIS OF VARIANCE FOR SHEAR PRESS DUPLICATES OF SIX TREATMENTS

Source	d. f.	Mean Squares
Treatments	5	266.05*
Replicates	2	14.24
Duplicates	1	3.42
Error	27	41.93

*Statistical significance at the 0.05 level of probability.

CHAPTER V

SUMMARY

The objective of this study was to compare the formulated freeze-dried strawberry puree slices with freeze-dried natural strawberry slices, and to see if any particular levels of the seven major variables led to a more desirable product (from the standpoint of texture) than the freeze-dried natural strawberry slices. The seven major variables studied were as follows:

1. Effect of amount and type of sugar
2. Effect of method of blending
3. Effect of method of freezing of the strawberries used
4. Effect of amount of blending water
5. Effect of amount and type of stabilizer
6. Effect of deaeration immediately following the blending process
7. Effect of temperature of blending water.

Under the conditions of the experiment reported in this paper, it was found that:

1. In general, sucrose appeared to have a slightly better effect on texture than corn sirup.

2. The texture for samples containing no sugar was very good as measured by all tests.

3. Texture appeared to improve as sugar level increased within either of the two sugar categories.

4. Differences between replicates occurred in the panel test with respect to two of the seven effects.

5. Dispersion of the colloidal stabilizer by stirring into 95 per cent ethanol caused texture to be significantly poorer than the texture of the control and the texture of formulated slices prepared by sifting the stabilizer into the vortex of the blending water.

6. Air blast freezing (-29° C.), liquid nitrogen freezing (-196° C.), and Freon Twelve freezing (-30° C.) of the strawberries were not significantly different in their effect on texture.

7. Freeze-dried formulated strawberry slices prepared from the strawberries frozen in each of these three ways had significantly poorer texture than the control.

8. Duncan's multiple range test for panel test showed that the control and the formulated slices in which the amount of blending water was 200 ml. (in the standard size batch) were significantly different.

9. The formulated product in which the amount of blending water was 100 ml. was shown to have a significantly poorer texture (based on panel test) than the control or the 200 ml. sample.

10. Duncan's multiple range test for the height test gave the following ranking (with best texture first and poorest last): 200 ml. of blending water; control; and 100 ml. of blending water. All three

treatments were significantly different.

11. Based on the criterion of three or more of the five texture tests being significantly superior to the control (by L. S. D. at the 0.05 level) or lacking significant difference from the control (by L. S. D. at the 0.05 level) or a combination of the two, seven stabilizer treatments were considered to have promise. The seven were as follows: Hercules CMC, 1.00 gm.; Velatex Gelatin, 4.50 gm.; Pad Guar Gum, 1.00 gm.; Kelgin MV, 1.00 gm.; Kelcoloid LVF, 1.00 gm., dispersed in ethanol; Supercol F, 0.40 gm.; and low methoxyl pectin, 1.00 gm. (with no calcium chloride added).

12. The deaerated product was not significantly different from the control, but both were significantly better than the texture of the sample which had not been deaerated.

13. The product prepared by using blending water at 30° C. was not significantly different from the control. Both the control and the 30° C. sample were significantly better than the sample prepared with blending water at 100° C.

14. The four objective tests arranged in decreasing order of their value as predictors of panel score were as follows: shatter, height, shear, and spread. The final value for the multiple R was 0.68 after all of the independent variables had been entered.

15. The analysis of variance for shear press duplicates for six treatments revealed that the difference between duplicates was not significant at the 0.05 level.

16. Several treatments were not significantly different from the control at the 0.05 level, and several had a significantly poorer texture. In only two cases was a treatment significantly better than the control. These were as follows: 200 ml. of blending water as measured by height test (Duncan's multiple range at the 0.05 level), and Kelcoloid LVF, 1.00 gm., dispersed in ethanol, as measured by shear test (L. S. D. at the 0.05 level).

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LITERATURE CITED

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APPENDIX

TABLE XXIX

RESULTS OF PANEL TEST FOR THE EFFECT OF AMOUNT AND TYPE OF SUGAR ON THE TEXTURE OF FREEZE-DRIED FORMULATED STRAWBERRY SLICES

Treatment[1]	Replicate	Judges' Scores[2]				
		J 1	J 2	J 3	J 4	J 5
NS	1	3	2	4	5	5
NS	2	2	2	5	5	7
NS	3	3	2	4	6	4
S, 5 gm.	1	3	2	4	3	2
S, 5 gm.	2	1	1	2	1	1
S, 5 gm.	3	3	2	3	3	2
S, 10 gm.	1	2	1	2	2	4
S, 10 gm.	2	2	1	4	3	1
S, 10 gm.	3	2	2	1	3	2
S, 20 gm.	1	2	5	3	2	3
S, 20 gm.	2	3	3	6	7	7
S, 20 gm.	3	3	2	5	3	2
S, 30 gm.	1	4	2	5	3	1
S, 30 gm.	2	2	3	7	3	1
S, 30 gm.	3	2	2	3	2	3
S, 40 gm.	1	2	2	6	3	2
S, 40 gm.	2	1	6	7	3	3
S, 40 gm.	3	2	2	2	2	3
CS, 5 gm.	1	2	2	3	2	2
CS, 5 gm.	2	2	3	5	2	2
CS, 5 gm.	3	3	2	2	3	2
CS, 10 gm.	1	2	2	2	2	2
CS, 10 gm.	2	2	2	4	3	3
CS, 10 gm.	3	3	2	3	2	2
CS, 20 gm.	1	1	3	2	1	1
CS, 20 gm.	2	2	3	5	2	1
CS, 20 gm.	3	1	1	4	2	2
CS, 30 gm.	1	2	1	3	1	1
CS, 30 gm.	2	2	2	6	3	2
CS, 30 gm.	3	2	1	3	2	4
CS, 40 gm.	1	2	1	4	5	3
CS, 40 gm.	2	3	2	3	3	3
CS, 40 gm.	3	2	2	2	3	3

TABLE XXIX (continued)

Treatment[1]	Replicate	Judges' Scores[2]				
		J 1	J 2	J 3	J 4	J 5
Control	1	4	4	4	4	4
Control	2	4	4	4	4	4
Control	3	4	4	4	4	4

[1]Amounts are based on standard size batch. Symbols have the following meanings: NS, no sugar; S, sucrose; CS, corn sirup; and Control, control strawberries.

[2]Figures represent panel scores on a seven point hedonic scale.

TABLE XXX

RESULTS OF SHEAR, SHATTER, SPREAD, AND HEIGHT TESTS FOR THE EFFECT OF AMOUNT AND TYPE OF SUGAR ON THE TEXTURE OF FREEZE-DRIED FORMULATED STRAWBERRY SLICES[1]

Treatment[1]	Replicate	Test Scores[2]			
		Shear	Shatter	Spread	Height
NS	1	5.5	100.0	0.0	12.5
NS	2	23.5	80.0	6.7	25.0
NS	3	8.0	85.7	0.0	25.0
S, 5 gm.	1	6.5	55.6	71.4	50.0
S, 5 gm.	2	8.2	70.0	10.0	41.7
S, 5 gm.	3	5.8	54.5	28.6	46.2
S, 10 gm.	1	11.8	53.6	55.3	53.8
S, 10 gm.	2	12.0	74.1	48.7	38.4
S, 10 gm.	3	5.5	73.3	56.8	57.1
S, 20 gm.	1	13.5	80.8	33.3	16.7
S, 20 gm.	2	10.0	97.7	0.0	12.5
S, 20 gm.	3	6.8	94.9	10.5	37.5
S, 30 gm.	1	14.8	93.2	20.0	42.8
S, 30 gm.	2	13.2	96.4	0.0	50.0
S, 30 gm.	3	7.8	93.2	26.3	42.8
S, 40 gm.	1	21.5	97.8	30.0	57.1
S, 40 gm.	2	30.2	96.7	0.0	40.0
S, 40 gm.	3	22.2	99.1	52.6	62.5
CS, 5 gm.	1	4.0	80.0	16.7	11.1
CS, 5 gm.	2	4.5	75.0	22.0	9.1
CS, 5 gm.	3	4.0	30.0	10.0	27.3
CS, 10 gm.	1	4.0	75.0	10.0	45.4
CS, 10 gm.	2	4.5	75.0	20.9	36.4
CS, 10 gm.	3	8.2	76.8	7.0	38.5
CS, 20 gm.	1	2.5	37.6	35.3	57.1
CS, 20 gm.	2	6.0	61.1	23.5	40.0
CS, 20 gm.	3	2.2	29.4	33.3	62.5
CS, 30 gm.	1	10.5	45.4	19.0	38.5
CS, 30 gm.	2	6.8	60.3	25.0	50.0
CS, 30 gm.	3	29.8	71.4	15.8	20.0
CS, 40 gm.	1	27.0	96.4	26.3	14.3
CS, 40 gm.	2	11.8	88.5	9.5	14.3
CS, 40 gm.	3	8.8	100.0	7.1	14.3

TABLE XXX (continued)

Treatment[1]	Replicate	Test Scores[2]			
		Shear	Shatter	Spread	Height
Control	1	18.0	89.4	0.0	25.0
Control	2	12.7	89.2	0.0	25.0
Control	3	23.0	94.3	0.0	35.7

[1]The figures are based on the standard size batch. Symbols have the following meanings: NS, no sugar; S, sucrose; CS, corn sirup; and Control, control strawberries.

[2]The figures given have the following means: shear, pounds of force required to shear the slices, as measured by Kramer Shear Press; shatter, per cent of weight remaining after shatter test; spread, per cent increase in diameter during rehydration (one minute); and height, per cent decrease in height during rehydration (one minute).

TABLE XXXI

RESULTS OF PANEL TEST FOR THE EFFECT OF BLENDING METHOD ON THE TEXTURE OF FREEZE-DRIED FORMULATED STRAWBERRY SLICES

Treatment[1]	Replicate	Judges' Scores[2]				
		J 1	J 2	J 3	J 4	J 5
Sift	1	2	5	3	2	3
Sift	2	3	3	6	7	7
Sift	3	3	2	5	3	2
Ethanol	1	1	1	4	3	1
Ethanol	2	3	3	4	1	2
Ethanol	3	2	2	7	3	2
Control	1	4	4	4	4	4
Control	2	4	4	4	4	4
Control	3	4	4	4	4	4

[1]Symbols have the following meanings: Sift, sifted into vortex of water; Ethanol, dispersed (by stirring) in 95 per cent ethanol; and Control, control strawberries.

[2]Figures represent panel scores on a seven point hedonic scale.

TABLE XXXII

RESULTS OF SHEAR, SHATTER, SPREAD, AND HEIGHT TESTS FOR THE EFFECT OF BLENDING METHOD ON THE TEXTURE OF FREEZE-DRIED FORMULATED STRAWBERRY SLICES

Treatment[1]	Replicate	Test Scores[2]			
		Shear	Shatter	Spread	Height
Sift	1	13.5	80.8	33.3	16.7
Sift	2	10.0	97.7	0.0	12.5
Sift	3	6.8	94.9	10.5	37.5
Ethanol	1	12.8	69.2	21.4	33.3
Ethanol	2	6.5	83.3	20.0	45.4
Ethanol	3	12.2	82.4	30.0	50.0
Control	1	18.0	89.4	0.0	25.0
Control	2	12.7	89.2	0.0	25.0
Control	3	23.0	94.3	0.0	35.7

[1]Symbols have the following meanings: Sift, sifted into vortex of water; Ethanol, dispersed (by stirring) in 95 per cent ethanol; and Control, control strawberries.

[2]See footnote 2, Table XXX, page 128.

TABLE XXXIII

RESULTS OF PANEL TEST FOR THE EFFECT OF FREEZING METHOD ON THE TEXTURE OF FREEZE-DRIED FORMULATED STRAWBERRY SLICES

Treatment[1]	Replicate	Judges' Scores[2]				
		J 1	J 2	J 3	J 4	J 5
AB	1	1	2	3	3	1
AB	2	3	2	5	3	2
AB	3	2	2	6	3	3
N_2	1	1	2	2	3	1
N_2	2	3	2	6	4	2
N_2	3	2	1	5	3	3
F	1	1	2	4	2	1
F	2	2	2	5	2	2
F	3	2	2	4	3	3
C	1	4	4	4	4	4
C	2	4	4	4	4	4
C	3	4	4	4	4	4

[1]Symbols have the following meanings: AB, air blast (-29° C.); N_2, liquid nitrogen (-196° C.); Freon twelve (-30° C.); and C, control strawberries.

[2]Figures represent panel scores on a seven point hedonic scale.

TABLE XXXIV

RESULTS OF SHEAR, SHATTER, SPREAD, AND HEIGHT TESTS FOR THE EFFECT OF FREEZING METHOD ON THE TEXTURE OF FREEZE-DRIED FORMULATED STRAWBERRY SLICES

Treatment[1]	Replicate	Test Scores[2]			
		Shear	Shatter	Spread	Height
AB	1	6.0	62.0	15.2	41.7
AB	2	12.2	77.2	30.2	41.7
AB	3	4.0	67.9	26.7	41.7
N_2	1	8.8	73.5	24.4	50.0
N_2	2	11.5	73.1	22.7	41.7
N_2	3	22.2	64.5	0.0	46.7
F	1	16.0	69.7	26.1	50.0
F	2	17.5	61.2	9.1	42.8
F	3	14.2	84.0	21.7	50.0
C	1	18.0	89.4	0.0	25.0
C	2	12.7	89.2	0.0	25.0
C	3	23.0	94.3	0.0	35.7

[1]Symbols have the following meanings: AB, air blast (-29° C.); N_2, liquid nitrogen (-196° C.); F, Freon Twelve (-30° C.); and C, control strawberries.

[2]See footnote 2, Table XXX, page 128.

TABLE XXXV

RESULTS OF PANEL TEST FOR THE EFFECT OF AMOUNT OF WATER ON THE TEXTURE OF FREEZE-DRIED FORMULATED STRAWBERRY SLICES

Treatment[1]	Replicate	Judges' Scores[2]				
		J 1	J 2	J 3	J 4	J 5
100 ml.	1	2	2	3	2	1
100 ml.	2	2	2	4	3	2
100 ml.	3	2	2	5	3	2
200 ml.	1	2	5	3	2	3
200 ml.	2	3	3	6	7	7
200 ml.	3	3	2	5	3	2
Control	1	4	4	4	4	4
Control	2	4	4	4	4	4
Control	3	4	4	4	4	4

[1]Symbols have the following means: 100 ml. means 100 ml. of water; 200 ml. means 200 ml. of water; Control means control strawberries. Amounts are based on the standard size batch.

[2]Figures represent panel scores on a seven point hedonic scale.

TABLE XXXVI

RESULTS OF SHEAR, SHATTER, SPREAD, AND HEIGHT TESTS FOR THE EFFECT OF AMOUNT OF WATER ON THE TEXTURE OF FREEZE-DRIED FORMULATED STRAWBERRY SLICES

Treatment[1]	Replicate	Test Scores[2]			
		Shear	Shatter	Spread	Height
100 ml.	1	12.5	79.7	37.2	57.1
100 ml.	2	9.0	75.6	12.2	30.8
100 ml.	3	11.8	58.3	23.9	57.1
200 ml.	1	13.5	80.8	33.3	16.7
200 ml.	2	10.0	97.7	0.0	12.5
200 ml.	3	6.8	94.9	10.5	37.5
Control	1	18.0	89.4	0.0	25.0
Control	2	12.7	89.2	0.0	25.0
Control	3	23.0	94.3	0.0	35.7

[1]Symbols have the following meanings: 100 ml. means 100 ml. of water; 200 ml. means 200 ml. of water; Control means control strawberries. Amounts are based on the standard size batch.

[2]See footnote 2, Table XXX, page 128.

TABLE XXXVII

RESULTS OF PANEL TEST FOR THE EFFECT OF KIND AND AMOUNT OF STABILIZER ON THE TEXTURE OF FREEZE-DRIED FORMULATED STRAWBERRY SLICES

Treatment[1]	Replicate	Judges' Scores[2]				
		J 1	J 2	J 3	J 4	J 5
1	1	2	5	3	2	3
1	2	3	3	6	7	1
1	3	3	2	5	3	2
2	1	1	1	5	3	4
2	2	2	2	3	6	3
2	3	2	1	3	3	3
3	1	1	1	4	2	1
3	2	1	1	2	3	2
3	3	2	2	4	2	2
4	1	1	1	3	1	1
4	2	2	1	2	1	1
4	3	1	1	2	2	2
5	1	2	2	2	4	4
5	2	4	2	3	2	3
5	3	2	2	3	3	3
6	1	1	1	2	2	1
6	2	2	1	4	3	2
6	3	2	1	2	2	2
7	1	1	1	3	1	1
7	2	1	1	3	2	1
7	3	1	1	3	1	1
8	1	3	5	2	5	6
8	2	3	6	6	6	7
8	3	4	6	1	4	3
9	1	1	1	3	1	1
9	2	1	2	4	1	2
9	3	2	3	6	2	3
10	1	5	3	4	5	3
10	2	3	2	5	3	6
10	3	3	3	5	3	3
11	1	2	2	4	2	1
11	2	3	2	3	3	3
11	3	3	2	6	3	3
12	1	2	2	3	2	2
12	2	2	1	3	3	3
12	3	3	2	4	3	3

TABLE XXXVII (continued)

Treatment[1]	Replicate	Judges' Scores[2]				
		J 1	J 2	J 3	J 4	J 5
13	1	4	3	2	3	3
13	2	3	2	6	3	2
13	3	3	2	4	3	3
14	1	1	1	4	1	3
14	2	4	2	5	3	3
14	3	2	1	1	1	1
15	1	3	2	5	3	3
15	2	4	1	3	2	3
15	3	3	3	2	3	3
16	1	2	2	6	3	3
16	2	3	2	4	3	3
16	3	3	3	1	3	3
17	1	2	1	6	2	3
17	2	3	2	3	3	4
17	3	3	2	4	3	3
18	1	2	2	5	3	3
18	2	3	1	1	2	2
18	3	3	2	3	3	2
19	1	3	1	5	2	3
19	2	3	2	2	3	3
19	3	3	2	5	3	2
20	1	2	1	1	4	2
20	2	3	2	1	3	3
20	3	2	1	2	2	1
21	1	1	2	3	2	2
21	2	2	1	3	2	1
21	3	3	2	3	3	1
22	1	1	1	5	1	1
22	2	2	1	3	1	1
22	3	2	1	2	2	1
23	1	1	1	3	1	1
23	2	2	1	2	1	1
23	3	2	1	2	1	1
24	1	1	2	4	1	1
24	2	2	1	2	2	1
24	3	2	1	2	2	1
25	1	1	1	3	1	1
25	2	1	1	1	2	1
25	3	2	1	1	1	1

TABLE XXXVII (continued)

Treatment[1]	Replicate	Judges' Scores[2]				
		J 1	J 2	J 3	J 4	J 5
26	1	1	1	4	1	1
26	2	2	1	1	2	1
26	3	2	1	2	1	1
27	1	2	2	5	2	1
27	2	2	1	2	1	1
27	3	1	1	3	3	1
28	1	1	1	4	2	1
28	2	2	2	4	3	1
28	3	3	2	4	2	2
29	1	1	1	5	2	1
29	2	2	1	4	2	1
29	3	3	1	3	3	2
30	1	2	2	5	3	1
30	2	3	2	5	3	2
30	3	3	2	4	3	3
31	1	1	1	1	2	1
31	2	1	1	2	1	1
31	3	2	1	2	2	2
32	1	1	1	1	1	1
32	2	1	1	1	2	1
32	3	3	2	2	3	2
33	1	2	2	3	4	2
33	2	3	2	3	3	2
33	3	3	2	1	3	2
34	1	2	2	6	3	1
34	2	4	2	4	3	3
34	3	4	3	6	3	3
35	1	1	1	4	1	1
35	2	1	1	5	2	1
35	3	1	1	2	1	1
36	1	1	1	3	1	1
36	2	1	1	2	2	2
36	3	2	1	3	2	1
37	1	1	1	4	2	1
37	2	3	2	6	3	2
37	3	3	2	4	3	2
38	1	4	4	4	4	4
38	2	4	4	4	4	4
38	3	4	4	4	4	4

[1]For the description of the treatments corresponding to these numbers, see Table XVIII, page 84.

[2]Figures represent panel scores on a seven point hedonic scale.

TABLE XXXVIII

RESULTS OF SHEAR, SHATTER, SPREAD, AND HEIGHT TESTS FOR THE EFFECT OF KIND AND AMOUNT OF STABILIZER ON THE TEXTURE OF FREEZE-DRIED FORMULATED STRAWBERRY SLICES

Treatment[1]	Replicate	Test Scores[2]			
		Shear	Shatter	Spread	Height
1	1	13.5	80.8	33.3	16.7
1	2	10.0	97.7	0.0	12.5
1	3	6.8	94.9	10.5	37.5
2	1	6.8	91.4	40.5	30.0
2	2	13.8	67.8	28.6	30.0
2	3	6.8	74.5	25.0	33.3
3	1	5.0	78.6	39.5	50.0
3	2	14.2	75.0	22.4	41.7
3	3	17.0	84.0	14.0	30.0
4	1	3.2	59.5	20.0	45.4
4	2	10.5	55.9	15.2	50.0
4	3	7.0	88.6	7.8	25.0
5	1	5.5	54.5	13.6	33.3
5	2	15.0	72.4	27.3	33.3
5	3	18.5	86.4	18.2	36.4
6	1	6.5	49.0	39.1	53.8
6	2	10.8	45.0	28.3	50.0
6	3	10.2	33.3	16.3	50.0
7	1	11.5	75.6	50.0	50.0
7	2	13.2	95.4	89.5	33.3
7	3	18.5	75.8	60.0	40.0
8	1	20.8	100.0	26.1	6.7
8	2	25.8	100.0	52.6	23.1
8	3	19.8	100.0	52.6	0.0
9	1	4.5	87.3	0.0	30.8
9	2	7.2	23.8	0.0	50.0
9	3	5.8	42.0	0.0	53.3
10	1	13.8	86.2	20.5	23.1
10	2	13.5	96.5	5.3	16.7
10	3	13.5	83.8	16.7	42.9
11	1	8.5	85.8	0.0	50.0
11	2	6.2	72.6	4.3	20.0
11	3	5.5	82.0	0.0	41.7
12	1	9.0	82.6	26.2	50.0
12	2	6.2	78.3	33.3	50.0
12	3	8.2	78.9	20.9	41.7

TABLE XXXVIII (continued)

Treatment[1]	Replicate	Test Scores[2]			
		Shear	Shatter	Spread	Height
13	1	8.0	94.5	18.2	33.3
13	2	8.0	88.0	0.0	16.7
13	3	7.0	88.6	2.4	14.3
14	1	5.8	12.8	0.0	40.0
14	2	4.5	47.9	11.6	41.7
14	3	7.8	75.8	15.8	33.3
15	1	17.2	83.3	10.0	25.0
15	2	14.2	75.0	0.0	33.3
15	3	12.5	92.3	0.0	35.7
16	1	13.5	100.0	20.9	15.4
16	2	20.8	100.0	31.7	38.5
16	3	10.2	88.9	27.2	28.6
17	1	16.0	71.4	0.0	28.6
17	2	8.8	93.3	39.5	33.3
17	3	16.8	78.5	20.0	25.0
18	1	30.8	96.0	20.9	33.3
18	2	17.0	100.0	25.0	33.3
18	3	18.2	100.0	32.6	28.6
19	1	22.8	100.0	2.2	33.3
19	2	43.0	82.0	0.0	35.7
19	3	31.0	81.5	20.5	33.3
20	1	6.2	18.8	6.4	42.8
20	2	6.2	59.1	8.9	38.5
20	3	2.0	40.8	8.7	38.5
21	1	5.2	92.0	42.8	38.5
21	2	6.0	75.0	7.0	30.8
21	3	14.8	81.5	17.1	33.3
22	1	5.5	55.6	5.9	46.2
22	2	3.8	70.0	14.9	53.8
22	3	4.5	54.5	13.4	50.0
23	1	5.2	43.2	14.3	50.0
23	2	6.0	28.8	4.4	57.1
23	3	4.8	17.0	15.2	45.4
24	1	6.5	49.3	15.2	53.8
24	2	8.2	53.8	20.4	50.0
24	3	6.5	38.3	21.8	38.5
25	1	5.8	47.2	4.2	50.0
25	2	4.2	39.4	38.9	60.0
25	3	5.5	40.0	13.6	56.2

TABLE XXXVIII (continued)

Treatment[1]	Replicate	Test Scores[2]			
		Shear	Shatter	Spread	Height
26	1	5.2	73.5	25.0	46.2
26	2	7.0	28.1	0.0	40.0
26	3	6.5	52.6	16.3	50.0
27	1	7.0	83.3	20.9	57.1
27	2	4.2	51.4	13.6	60.0
27	3	5.2	42.8	15.2	33.3
28	1	8.8	47.2	20.0	53.8
28	2	7.2	68.2	15.2	50.0
28	3	8.2	73.9	35.7	53.8
29	1	5.8	56.5	17.4	53.8
29	2	8.8	50.0	23.8	47.0
29	3	4.8	71.4	12.5	45.4
30	1	6.2	60.0	13.6	42.8
30	2	9.2	96.6	4.3	56.2
30	3	7.0	72.9	22.7	46.2
31	1	3.8	72.0	8.5	50.0
31	2	7.5	22.7	36.4	36.4
31	3	7.2	40.0	27.3	46.1
32	1	4.5	25.7	8.9	53.8
32	2	4.5	47.0	8.9	38.5
32	3	5.2	38.8	0.0	41.7
33	1	6.5	55.2	4.6	20.0
33	2	8.5	29.0	0.0	71.4
33	3	7.5	24.6	11.4	28.6
34	1	8.5	83.3	7.0	33.3
34	2	13.2	100.0	2.3	14.3
34	3	10.0	78.0	0.0	35.7
35	1	4.5	25.0	50.0	58.3
35	2	7.5	90.0	30.0	58.3
35	3	4.5	62.2	20.4	58.3
36	1	4.5	72.7	4.3	53.8
36	2	4.8	31.8	8.7	53.3
36	3	4.0	65.0	10.0	38.5
37	1	7.2	59.6	0.0	38.5
37	2	9.5	72.6	2.2	26.7
37	3	7.0	65.3	19.1	43.8

TABLE XXXVIII (continued)

Treatment[1]	Replicate	Test Scores[2]			
		Shear	Shatter	Spread	Height
38	1	18.0	89.4	0.0	25.0
38	2	12.7	89.2	0.0	25.0
38	3	23.0	94.3	0.0	35.7

[1]For the description of the treatments corresponding to these numbers, see Table XVIII, page 84.

[2]See footnote 2, Table XXX, page 128.

TABLE XXXIX

RESULTS OF PANEL TEST FOR THE EFFECT OF DEAERATION ON THE TEXTURE OF FREEZE-DRIED FORMULATED STRAWBERRY SLICES

Treatment[1]	Replicate	Judges' Scores[2]				
		J 1	J 2	J 3	J 4	J 5
ND	1	4	2	5	3	1
ND	2	2	3	7	3	1
ND	3	2	2	3	2	3
D	1	1	3	7	3	5
D	2	5	3	6	5	3
D	3	3	3	6	5	3
C	1	4	4	4	4	4
C	2	4	4	4	4	4
C	3	4	4	4	4	4

[1]Symbols have the following meanings: ND, not deaerated; D, deaerated; and C, control strawberries.

[2]Figures represent panel scores on a seven point hedonic scale.

TABLE XL

RESULTS OF SHEAR, SHATTER, SPREAD, AND HEIGHT TESTS FOR THE EFFECT OF DEAERATION ON THE TEXTURE OF FREEZE-DRIED FORMULATED STRAWBERRY SLICES

Treatment[1]	Replicate	Test Scores[2]			
		Shear	Shatter	Spread	Height
ND	1	14.8	93.2	20.0	42.8
ND	2	13.2	96.4	0.0	50.0
ND	3	7.8	93.2	26.3	42.8
D	1	24.0	93.8	10.0	0.0
D	2	63.5	88.5	9.1	0.0
D	3	15.0	90.0	13.0	50.0
C	1	18.0	89.4	0.0	25.0
C	2	12.7	89.2	0.0	25.0
C	3	23.0	94.3	0.0	35.7

[1]Symbols have the following meanings: ND, not deaerated; D, deaerated; and C, control strawberries.

[2]See footnote 2, Table XXX, page 128.

TABLE XLI

RESULTS OF PANEL TEST FOR THE EFFECT OF WATER TEMPERATURE ON THE TEXTURE OF FREEZE-DRIED FORMULATED STRAWBERRY SLICES

Treatment[1]	Replicate	Judges' Scores[2]				
		J 1	J 2	J 3	J 4	J 5
30° C.	1	2	5	3	2	3
30° C.	2	3	3	6	7	7
30° C.	3	3	2	5	3	2
100° C.	1	2	2	6	2	1
100° C.	2	3	2	7	2	3
100° C.	3	3	2	3	3	4
C	1	4	4	4	4	4
C	2	4	4	4	4	4
C	3	4	4	4	4	4

[1]Symbols have the following meanings: 30° C., blending water at 30° C.; 100° C., blending water at 100° C.; and C, control strawberries.

[2]Figures represent panel scores on a seven point hedonic scale.

TABLE XLII

RESULTS OF SHEAR, SHATTER, SPREAD, AND HEIGHT TESTS FOR THE EFFECT OF WATER TEMPERATURE ON THE TEXTURE OF FREEZE-DRIED FORMULATED STRAWBERRY SLICES

Treatment[1]	Replicate	Test Scores[2]			
		Shear	Shatter	Spread	Height
30° C.	1	13.5	80.8	6.8	33.3
30° C.	2	10.0	97.7	11.1	0.0
30° C.	3	6.8	94.9	8.7	10.5
100° C.	1	8.2	80.8	6.8	46.7
100° C.	2	7.8	73.3	11.1	43.8
100° C.	3	9.5	94.2	8.7	46.7
C	1	18.0	89.4	0.0	25.0
C	2	12.7	89.2	0.0	25.0
C	3	23.0	94.3	0.0	35.7

[1]Symbols have the following meanings: 30° C., blending water at 30° C.; 100° C., blending water at 100° C.; and C, control strawberries.

[2]See footnote 2, Table XXX, page 128.

TABLE XLIII

RESULTS OF DUPLICATE SHEAR PRESS TESTS
FOR SIX TREATMENTS

Treatment	Replicate	Shear Values[1] Trial One	Trial Two
No sugar	1	5.5	14.2
No sugar	2	23.5	6.2
No sugar	3	8.0	34.5
Sucrose, 20 gm.	1	13.5	9.5
Sucrose, 20 gm.	2	10.0	9.5
Sucrose, 20 gm.	3	6.8	5.2
Sucrose, 30 gm.	1	14.8	16.8
Sucrose, 30 gm.	2	13.2	15.0
Sucrose, 30 gm.	3	7.8	10.2
Sucrose, 40 gm.	1	21.5	23.2
Sucrose, 40 gm.	2	30.2	24.2
Sucrose, 40 gm.	3	22.2	23.2
Corn sirup, 20 gm.	1	2.5	3.2
Corn sirup, 20 gm.	2	6.0	6.5
Corn sirup, 20 gm.	3	2.2	5.0
Corn sirup, 30 gm.	1	10.5	10.0
Corn sirup, 30 gm.	2	6.8	15.5
Corn sirup, 30 gm.	3	29.8	14.0

VITA

The author was born August 17, 1944, in Knoxville, Tennessee. He was graduated from Maury High School, Dandridge, Tennessee, in 1962. From 1962 until 1966 he attended The University of Tennessee, Knoxville; he received a Bachelor of Science degree in Food Technology in the latter year. In September 1966, he entered The University of Tennessee Graduate School. Since that time he has been working to complete the requirements for the degree, Master of Science.