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THE EFFECT OF THAWING RATE ON
TEXTURAL QUALITY OF FROZEN BLUEBERRIES

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THE EFFECT OF THAWING RATE ON TEXTURAL QUALITY OF FROZEN BLUEBERRIES

By

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ABSTRACT

THE EFFECT OF THAWING RATE ON
TEXTURAL QUALITY OF FROZEN BLUEBERRIES

By

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Blueberries of the Jersey variety (Vaccinium lamarckii) were individually quick frozen in air-blast and by immersion in each of propylene glycol and sucrose solutions. Different thawing rates were obtained during this study by varying the medium of thawing and the temperature of the thawing medium. The effect of these thawing rates on the textural quality (determined using an objective method of measurement) after thawing of the frozen blueberries was found to be significant at the 5% level and the relationship between the rate of thaw and texture of the berries was analyzed and concluded to be a second-order polynomial. The degree of correlation between the objective and sensory methods that were used in evaluating texture of thawed blueberries was found to be relatively low, though significant at the 5% level for berries thawed in air-blast.

To My Loving Mother

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INTRODUCTION

Fruits and vegetables preserved commercially by freezing and frozen storage would have to be thawed before utilization. Thawing has, however, been shown to be inherently slower than freezing when conducted under comparable temperature differentials and in practice, the maximum temperature differential permissible during thawing is much less than that which is feasible during freezing due to the sensitivity of foods to high temperatures.

Apart from the fact that thawing takes longer than freezing, an additional concern is the temperature at which it occurs; i.e. the time-temperature pattern characteristic of thawing is potentially more detrimental than that of freezing, for during thawing, the temperature rises rapidly to near the melting point and remains there throughout the long course of thawing, thus affording considerable opportunity for occurrence of chemical reactions, recrystallization and even microbial growth if thawing is extremely slow.

As a consequence of the above-mentioned factors, greater damage to food texture could be brought about by thawing than by freezing. Thawing damage could, however, be lessened if: (1) more were known concerning optimum thawing procedures for various kinds of foods, (2) frozen foods were marketed in a form (suitable size, shape and package) conducive to good thawing procedures, and (3) adequate instructions for thawing were provided with each product.

The main purposes of this research were to investigate the effect of various thawing procedures (applied on frozen blueberries) on the textural quality of the berries and to determine the degree of correlation between the objective and sensory methods of texture evaluation.

LITERATURE REVIEW

Food texture has been described by Finney (1969) to be the sum total of kinaesthetic sensations derived from eating a food, for it encompasses the mouthfeel, the masticatory properties and the sound. According to Szczesniak (1963), textural characteristics can be classified under three main groups: mechanical, geometric and others. The textural characteristics of fruits and vegetables were defined by Mackey, et al., (1973), to be crispness, juiciness, firmness, toughness, mealiness and fibrousness. These characteristics were found to be associated with plant tissue, composition and structure of cell wall constituents, intercelluar binding tissue and the water relationships of the plant tissues.

Fruits and vegetables have been preserved commercially by freezing and frozen storage. During the freezing of plant tissue, cells have been found to separate along the middle lamella, which is probably the area of least resistance to mechanical forces from growing ice crystals (Woodroof, 1938). Weier and Stocking (1949) discovered that any weakening of the adhesive forces within the middle lamella brought about textural changes in plant tissues.

Gutschmidt (1968) reviewed the principles of freezing and low temperature storage applicable to fruits and vegetables and remarked that the retention of "natural quality" in a plant tissue depended upon maturity and quality of raw product, amount of handling between harvesting and processing, freezing, storage and thawing procedures.

Freezing has been defined by Fennema et al., (1973) to be a reduction in temperature, generally to 0°F or below and crystallization of part of the water and some of the solutes. Histological techniques were used by Reeve (1970) to ascertain that freezing a plant tissue led to the formation of ice crystals which in turn, punctured the cells of the tissue and also that when plant tissue was subjected to freezing followed by thawing, the net result was the withdrawal of more water into the intercellular spaces during freezing than was reabsorbed during thawing, which finally led to the destruction of the colloidal complex of cells.

Joslyn (1966), Fennema and Powrie (1964) and Gutschmidt (1968) reviewed an early theory that tissue damage during freezing results from the withdrawal of water from cell protoplasm to form ice in intercellular spaces. The amount of water withdrawn from the protoplasm of the cell of a fruit is generally high for fruits have large intercellular spaces. This dehydration of the protoplasm would result in the deformation of cell walls and overall loss in textural quality of the tissue.

Plant tissues contain protein-water gels and carbohydrate-water gels. Gutschmidt (1968) found that water separated out of these gels during freezing. Ponting, et al., (1968), reported that when colloidal solutions in cell membranes became dehydrated, changes in permeability and elasticity of the membranes occurred, so that loss of rigidity resulted upon thawing; i.e. a frozen fruit on thawing appeared soft and mushy.

Morris (1968) reviewed work on effects of freezing rate on hydrogels and he found that rapid freezing resulted in less dehydration of the colloidal material than slow freezing. He also found that more water was reabsorbed with less drip occurring during thawing of colloidal matter subjected to rapid freezing than to slow freezing. This same researcher reviewed findings on protoplasm denaturation during freezing and remarked that it was impossible, even with the fastest freezing methods, to prevent protoplasm denaturation during freezing and he finally concluded that the only advantage of quick freezing over slow freezing was the formation of smaller ice crystals which then resulted in less tearing and disruption of cell tissues.

Fennema and Powrie (1964) reported that though cells in many fruits are susceptible to mechanical rupture during growth of ice crystals, resulting in "soft and limp thawed product with excess drip", rapid freezing may however, minimize cell damage and reduce the excessive amount of fluid loss upon thawing for small, uniformly dispersed ice crystals are formed in the frozen tissue after rapid freezing.

Joslyn (1966) reviewed findings of several researchers on the effect of freezing rate on texture of plant tissues and observed that "quick freezing based on refrigerant temperatures of -33°F to -40°F, results in less tissue rupture."

Various techniques and materials have been used for quick freezing fruits. Bartlett and Brown (1964) referred to direct contact freezing in sugar solutions and described their "polyphase process" for rapid freezing to be a process which employed a heat transfer medium of invert sugar solution that had been agitated and simultaneously chilled until a disperse solid phase of very small ice crystals was formed. In 1969, E. I. Dupont de Nemours introduced a system for direct contact freezing of foods with liquid "freon" freezant (Anon, 1969). MacArthur (1945), Fennema and Powrie (1964) and Ponting, et al., (1968) reported that rapid freezing of strawberries in liquid nitrogen was feasible.

The freezing process is usually followed by the frozen storage period and the time period that frozen foods can be maintained in "good condition" depends on the kind of product, how it is processed and packaged, and the storage temperature. In the United States, 0°F is generally accepted as a satisfactory storage temperature for frozen foods, according to Fennema, et al., (1973) and Fennema (1975); however, these authors also stated that frozen foods stored at or near a conventional temperature of 0°F are not completely frozen nor are they inert, for they deteriorate at a significant rate and the qaulity loss incurred during a normal period of frozen storage generally exceeds that caused by any other phase of the freezing process via prefreezing treatments, freezing and thawing. The loss of quality during proper frozen storage of foods could be attributed to chemical and/or physical means since microorganisms can not grow under these conditions.

The major physical changes that occur during frozen storage are recrystallization, and sublimation. Dyer (1951) and Dykstra (1956) reported that recrystallization was partially responsible for the disappearance during frozen storage, of the quality advantages initially apparent in rapidly frozen foods as compared to slowly frozen foods. Sublimation of ice can occur during frozen storage of improperly packaged frozen food and this can lead to a defect known as "freezer burn." Recrystallization can be effectively controlled by storing products at a constant low temperature and for a minimal time while sublimation can be minimized by any means which effectively stops loss of moisture from the product; e.g. application of an ice glaze (fish) or packaging with a material which is highly impermeable to water vapor.

The chemical changes that occur in foods during frozen storage are the degradation of pigments and vitamins, insolubilization or destabilization of proteins, oxidation of lipids, reactions which lead to diminished differences in quality between rapidly and slowly frozen foods, and reactions which cause an increase in the amount of thaw exudate from tissue as the time of frozen storage is extended. Fennema et al., (1973) reported that they found that most of these chemical reactions occurred slowly at 0°F and declined further in rate as the temperature was reduced; and also that during the early stages of freezing some reactions, including glycolysis, actually increased in rate while others decreased in rate less than expected.

Thawing of food, which constitutes the last phase of the freezing process before utilization, is believed to be potentially more damaging than freezing because of the following reasons: (1) thawing of non-fluid foods (tissue, gels) is inherently slower than freezing when comparable temperature differentials (i.e. difference in temperatures between the food and the cooling or heating medium) are employed (Rinfret, 1960) due to the fact that during thawing, the temperature rises rapidly to near the melting point and remains there for a relatively long time before it continues to rise; (2) temperature differentials frequently are less during thawing than during freezing, especially with fruits. During thawing, foods are subject to damage by chemical, physical, and microbial means, although microbial problems are negligible in properly handled foods, and as a result of these considerations, thawing should be regarded as a greater potential source of damage than freezing (Fennema and Powrie, 1964), but Gutschmidt (1968), reported that thawing may affect the properties of fruits to the same extent as freezing.

Luyet (1968a; 1968b) found that during slow thawing, large ice crystals developed at the expense of smaller ones; i.e. migration of molecules from smaller to larger ice crystals took place. He called this phenomenon, "migratory recrystallization", and noted that it occurred most rapidly at near freezing temperatures. Fennema and Powrie (1964) also reported recrystallization occurring at a more rapid rate near the freezing point of tissue. MacKenzie and Luyet (1967) found that recrys-tallization was more evident in rapidly frozen as compared with slowly frozen gelatin gels if these gels were thawed slowly.

Although food quality could be seriously impaired during thawing, the time involved would be short compared to a normal period of frozen storage. As a result, loss of quality might be greater during frozen storage (as conducted commercially) than during thawing, and the evidence for this statement came from the observation made by Fennema and Powrie (1964) that some foods could be rapidly frozen and thawed (no frozen storage) without incurring appreciable damage.

Commercially, dielectric and microwave heating had received some attention as possible means of thawing foods; for it had been found that provided the food material was reasonably homogenous, dielectric or microwave heating would enable more rapid and more uniform heating than would be possible by thermal conduction (Copson, 1962; Cable, 1954). Unfortunately, foods being thawed are not reasonably homogenous, since frozen and unfrozen phases exist simultaneously and these phases heat at markedly different rates when placed in a dielectric field, which often leads to localized overheating before all areas have thawed.

For use in the home, most vegetables can be thawed and cooked by direct immersion in boiling water, but since high temperatures are detrimental to the quality of most fruits, they therefore must be thawed under milder temperature conditions than vegetables. Suitable tech-niques that are presently used consist of placing unopened packages of fruit at room temperature, in the refrigerator, or in cool to slightly warm water until thawing is almost complete. Fruits should be consumed promptly after thawing because their color and texture deteriorate rapidly at this point.

In quality control, it is important to identify, measure, and control independently each of the significant components of quality (Kramer and Twigg, 1966). Texture is an important component of food quality and, in certain foods, may be even more important than flavor and appearance (Szczesniak and Kleyn, 1963). Measurement of food texture, therefore, plays a significant role in the food industry, via product development and improvement, control of manufacturing processes, and in the evaluation of the quality of the finished product to be consumed.

According to Finney (1969), texture, or the kinesthetic characteristics of foods is generally considered to relate to those attributes of quality associated with the sense of feel, as experienced either by the fingers, the hand or in the mouth. It includes such sensations as hardness, tenderness, brittleness, mealiness, crispness, etc., but excludes the sensations of temperature and pain. Objective measurements of food texture, therefore, have involved predominantly an analysis of the mechanical or rheological behavior of food materials; that is, their deformation, strain, or flow characteristics when subjected to a mechanical force.

Instruments used on solid foods can be divided into cutting, piercing, puncturing, compressing or shearing devices. Generally, emperical texture testing systems are devices which contain four basic elements, via (1) a probe containing the food sample; (2) a driving mechanism for imparting motion in a vertical, horizontal or rotational direction; (3) a sensing element for detecting the resistance of the foodstuff to the applied force; and (4) a read-out system for quantifying the resistance of the specimen.

The deformation of a food under the influence of a force is frequently used as a measure of quality. Brinton and Bourne (1972) classified foods that deform to a small extent as "firm", "hard", or "rigid", while foods that deform to a large extent are classified as "soft", "flaccid", or "spongy". They also reported that softness may be associated with good or poor quality depending on the food.

Hardness is a textural characteristic of foods evaluated organoleptically during the "first bite" of the masticatory cycle (Brandt et al., (1963). At this time the chewing force is applied to the food in an approximately linear manner which can be satisfactorily reproduced instrumentally by compression testing with the Instron Universial Tensile Tester (Shama and Sherman, 1973). However, the relationship between force and compression exhibited by this instrument depends on the cross-head speed utilized and it is therefore necessary to closely simulate the mechanical conditions prevailing during the initial stage of mastication if instrumental data are to be utilized to predict the sensory evaluation of hardness. The importance of selecting the correct instrumental test conditions is further emphasized by observations that larger chewing forces are applied to hard than to soft foods and that the rate of chewing for these two categories also varies. Studies with fruit and vegetables indicate that when the consumer judges firmness by squeezing samples between the fingers, the rate at which the force is applied and the maximum force also depend on product firmness (Voisey and Crete, 1973).

Although various objective and subjective methods have been proposed for measuring textural quality of fruits, the correlation of these methods has, in most cases, been difficult due mainly to the fact that the rate of force application in sensory testing is significantly greater than that customarily used in instrumental tests. It is however, strongly desirable for one to know how selected objective methods compare with human senses in their ability to detect and quantify texture parameters.

MATERIALS AND METHODS

Raw Product

The Jersey variety of blueberries (*Vaccinium lamarckii*) was used in this study. Two sets of blueberries which weighed about 4 Kg each were purchased during the second half of the month in July, 1977 at the Municipal Market in Lansing, Michigan. Each of the two sets had been hand-harvested a day prior to being brought to the Municipal Market at De Grandchamp, South Haven, Michigan. The second set was purchased a week after purchasing the first set of berries.

Equipment Used

The equipment used in this study for freezing, frozen storage and thawing were the following:

1) Two identical "Low Temperature-High Temperature" test chambers, Model SK-3105, produced by Associated Testing Laboratories, Inc., 200 Route 46, Wayne, New Jersey, 07470.
2) Two "Constant Temperature" Laboratory Baths (Cat. Nos. 4-8600 and 4-8600A), each equipped with a "Quickset" Bimetal thermoregulator (Cat. No. 4-235F). These baths were manufactured by American Instrumental Co., Inc., 8030 Georgia Avenue, Silver Spring, Maryland, 20910. A mercury thermometer, whose calibration was verified by immersion in ice water slurry, was used to set the thermoregulators at the desired freezing and thawing temperatures.
3) A Multi/Riter Recorder produced by Texas Instruments Incorporated, Houston, Texas. Thermocouples attached to this temperature recorder were made of copper, 0.46 cm in diameter and constantan

0.48 cm diameter. The chart speed used was 1.0 inch per minute (2.5 cm per minute) while the print speed obtained with the selected change gear ratio of 2.5:1 was 5 seconds between points. The chart paper used had a temperature range of -100°F to 100°F. The calibration of the Multi/Riter Recorder was checked and found to record temperature values at 2°F below actual temperature values as recorded by the mercury thermometer mentioned above. Temperature values shown in the various tables of data were all corrected to compensate for the above error (i.e. 2°F was added to the strip chart measurements).

4) The Instron Universal Testing Machine, Model TTBM, Serial No. 1950, produced by Instron Corporation, Canton, Massachussetts. The diameter of the compression cell (probe) used was 5.5 cm. The cross-head speed used was 20 cm/minute (high) while the chart speed used was 30 cm/minute. The selector of the "Full Scale Load" was set on 1, and only the peak height recorded on the chart paper was measured.

Preparation of Samples

In the laboratory, sorting of each 4 Kg set of purchased berries was done in order to remove bruised berries and foreign materials; and also to have only berries with the minimum height (measured using calipers) of 1.10 cm and minimum width of 1.50 cm. The average and maxiumum values of the height and width of the berries were not determined. Ten berries removed at random from the remaining batch of each set of blueberries purchased were weighed (using a Mettler balance) and the average weight per berry was 1.87 gm in the first set and 1.90 gm in the second set. The remaining batch of blueberries from each set was divided into two portions and each portion (though one of the two portions was kept in the refrigerator for about 30 minutes, while the other was being processed) was rinsed with cold tap water and quickly arranged in a single layer on a sieve No. 8 of the U. S. Standard Sieve Series which had a pore opening of 2.38 mm. The sieve mesh was positioned horizontally and shaken gently at intermittent intervals during the subsequent draining which was done at an ambient temperature of 70°F for about five minutes. After the draining the berries from each set purchased at the same time were individually quick frozen, first in air, followed by immersion freezing using either propylene glycol solution or sucrose solution as outlined below.

Freezing Procedures

The freezing procedures used were the following:

Air-blast freezing--the air inside a "Low Temperature" test chamber was cooled down to -40°F and maintained at this constant temperature throughout the duration of the freezing treatment.

Immersion freezing in propylene glycol solution--propylene glycol (trade name--Dowfrost) was mixed with distilled water at room temperature to obtain a 50% (by volume) of Dowfrost solution which was equivalent to 53.5% (by weight) of Dowfrost solution (obtained from the conversion chart for aqueous solutions of Dowfrost that was supplied by the Dow Chemical Company, manufacturers of Dowfrost). The Dowfrost solution was poured inside the "Constant Temperature" Laboratory Bath (Cat. No. 4-8600A) to reach a height of about 25 cm, and the solution was cooled down to -20°F and maintained constant at this temperature with the aid of the bath.

Immersion freezing in sucrose solution--sucrose crystals were mixed with distilled water at room temperature to obtain a 30% (by weight) of sucrose solution which was checked for accuracy using the Abbe refractometer. The sucrose solution was put into a cylindrical pot of diameter 33 cm and height 24 cm. This pot was made of an enamel-coated metal (0.23 cm thick) and the pot which had been filled to a height of 15 cm with the sucrose solution was held securely in the "Constant Temperature" Laboratory Bath (Cat. No. 4-8600) which also contained 50% (by volume) Dowfrost solution at a constant temperature of -20°F and this Dowfrost solution reached a height of 18 cm on the exterior of the pot and through this arrangement the sucrose solution was able to be cooled down to 0°F. A wooden paddle was inserted in the pot and was used to break up and redissolve the hydrated sucrose molecules as they crystallized out of the solution throughout the pot. The manual, uninterrupted stirring (till freezing was completed) with the paddle, imparted some motion to the hydrated sucrose molecules and thereby, kept the temperature of the sucrose solution (which was continuously measured using the temperature recorder), at the desired temperature of 0°F.

To monitor the freezing rate in each of the above three media, the exposed ends (which were about 0.55 cm long) of thermocouples were pushed into the blueberries (from the point of attachment of the berry fruit to the stalk) in order to reach the geometric center of each fruit, which was determined by halving the average height of the berry and this was found to be approximately 0.55 cm between the end of the berry's attachment to the stalk and the inside of the berry. Markers (small paper cellotapes) were put on the thermocouples at distances of

0.55 cm from the exposed tips before these tips were inserted into the berries, while the other ends of the thermocouples were attached to the Multi/Riter Recorder. Freezing rate was determined by observing the time taken for the temperature at the geometric center to drop from ambient temperature (70°F) to the temperature of the freezing medium used.

The sorted and washed blueberries (from the first set purchased) weighing about 3.7 Kg were divided into two batches. One batch was spread out to form a single layer inside a 0.64 cm mesh-wire rectangular cage, 35 cm X 50 cm, and 9 cm high, which also had a lid. Three berries, each containing a thermocouple, were gently placed on the floor of the cage and part of each thermocouple wire inside the cage was taped to the wall of the cage in order to prevent movement of each of the three berries. The lid of the cage was closed before the cage was positioned in the center of the air-blast freezer. In this position, the cage was parallel to and also in the zone of the incoming blast of cold air (-40°F) for 10 minutes.

The second batch was spread out to form a single layer inside a wire-mesh cage similar to the above, which also had a similar arrangement of three berries into which thermocouples had been inserted. The cage, with the lid closed, was then immersed in propylene glycol solution (50% by volume) at -20°F for 4.5 minutes and the excess solution adhering to the sides of the cage and berries were quickly drained by gently tapping the sides of the cage.

The berries containing the thermocouples in each frozen batch of berries were removed from the "freezing cage" and put into a small tin can (8 cm high and 10 cm diameter) which was then covered with aluminum foil while the remaining frozen berries were poured from the cage into a 30-lb capacity tin can with a lid and both tin cans were placed in the storage chamber for 2-3 days at -10°F.

The sorted and washed blueberries (from the second set purchased) weighing about 3.75 Kg were also divided into two batches. One batch was frozen in the air-blast freezer as described above for the batch of berries from the first set purchased. The second batch was spread out in a single layer inside the "freezing cage" (as described above for the berries frozen by immersion in Dowfrost solution) and the cage was then immersed in 30% (by weight) sucrose solution at 0°F for four minutes, followed by quick draining of the excess sucrose solution at the surface of the berries and cage by gently tapping the sides of the cage. The berries containing the thermocouples in each frozen batch were prepared for storage as described above for the first set of berries purchased, while the remaining berries per frozen batch were poured into a 30-lb capacity tin can with a lid which was then placed in the storage chamber for 60-68 days at -10°F.

Storage Procedures

The storage tin cans which had previously been placed in the "Low Temperature-High Temperature" test chamber for about 30 minutes were then transferred, usually within 60 seconds after the berries would have been packed into the cans, back into the test chamber which was maintained at a temperature of -10°F. In the first set of experiments, the storage period was 2-3 days while in the second set of experiments, the storage period used was 60-68 days.

The temperature of the test chamber was recorded using a mercury thermometer (Taylor Co.) and for the storage period of 60-68 days, the temperature was observed to fluctuate from -10°F to -7°F occasionally. During sampling of the berries for the set of thawing operations, the freezer (test chamber mentioned above) door was opened and closed as quickly as possible in order to minimize the amount of warmer air from outside entering the freezer. Though the freezer temperature was observed to warm up to -2°F to -3°F, it however, usually returned to -10°F within a few minutes. Some fine ice crystals were observed along the inside walls of the cans kept in frozen storage for 60-68 days and it was believed that these were formed by the condensation of water vapor inside the cans, followed by crystallization of the liquid water.

Thawing Procedures

Samples of the frozen berries (each sample used for a specific thawing treatment weighed about 300 g) were removed from storage when needed and each sample was spread out to form a single layer inside a 0.64 cm mesh-wire rectangular cage, 35 cm X 50 cm, and 9 cm high with a lid and this served as the "thawing cage". Also three berries containing thermocouples which had been frozen in a similar manner as the 300 g sample above, were placed on the floor of the cage and part of each thermocouple wire inside the cage was taped to the wall of the cage in order to prevent movement of each of the three berries. The lid of the cage was closed before the cage was placed in any of the thawing media viz air-blast 50% (by volume) Dowfrost solution and 22.5% (by weight) of sucrose solution. The thawing procedures used were the following:

Air-blast thawing--the air inside a "Low Temperature-High Temperature" test chamber was warmed up to the desired thawing temperature and maintained constant at this temperature throughout the subsequent thawing treatment. The thawing temperatures used were 80°, 90° and 100°F.

Immersion thawing in propylene glycol solution--50% (by volume) Dowfrost solution was made using pure Dowfrost and distilled water at room temperature. This solution was warmed up to the desired thawing temperature and maintained constant at this temperature inside the Constant Laboratory Bath (Cat. No. 4-8600). The thawing temperatures used were 80°, 90° and 100°F.

Immersion thawing in sucrose solution--sucrose crystals were mixed with distilled water at room temperature to obtain a 22.5% (by weight) of sucrose solution which was checked for accuracy using the Abbe refractometer. The sucrose solution was warmed up to the desired thawing temperature and maintained constant at this temperature inside the laboratory bath (Cat. No. 4-8600). The thawing temperatures used were 80°, 90° and 100°F.

To monitor thawing rates for each thawing operation, the three thermocouples in the "thawing cage" described above, were attached to the Multi/Riter Recorder. The thawing rate for a berry, in °F/minute was calculated by determining the time in minutes for the temperatureat the geometric center of the berry to warm up from 20° to 40°F (for this temperature interval represents the approximate range where most of the ice to water change of state occurs). Each thawing operation was replicated so that the average of six thawing rates (each obtained from a berry) was calculated and used in this study.

Texture Measurements

The blueberries from the first set purchased were thawed in air-blast and propylene glycol solution. After a thawing operation, the berries were immediately packed into several small aluminum cups (6cm diameter and 4 1/2 cm high) and transferred within five minutes to the room housing the Instron Universal Testing Machine in an ice chest. The Instron had previously been calibrated and set ready for measurement before the berries were thawed. A total of ten berries (chosen at random) were removed one at a time from the cups in the ice chest and placed on a Whatman No. 1 filter paper of 11.0 cm diameter which was then placed on top of the gage (i.e. the platform of the Instron on which samples are placed). The Instron measurement on the first through the last of the ten berries was usually accomplished in about seven minutes. The remaining berries were then discarded after the Instron measurement had been done on the ten berries.

No sample holder was used, and all measurements were made with a full scale load of 1 kilogram and a cross-head speed of 20 cm/minute. Each berry was placed with the point of attachment to the stalk facing upwards and was compressed till the height was reduced from the initial value (which was about 1.10 cm) to 0.10 cm. The maximum compression force corresponding to the maximum peak height was recorded in grams in the results. No sensory evaluation of the firmness of the thawed blueberries was conducted on the first set of purchased berries.

The berries from the second set purchased which had been stored for 60-68 days were thawed in air-blast and sucrose solution. The sucrose solution was used in the second set of experiments, because the berries after thawing were analyzed for textural quality by a taste panel.

The 30% (by weight) sucrose solution was used during the freezing phase in order to obtain a cooled sucrose solution at 0°F while the 22.5% (by weight) sucrose solution was used during the thawing phase, so that the thawing medium was isotonic with the soluble solids content of the berries, which was determined using the Abbe refractometer to have an average value of 22.5° Brix. Immediately after each thawing operation, the berries were packed into trays, covered with aluminum foil and were kept in the refrigerator (temperature, 40°-42°F) for about 15 minutes before samples were taken out for sensory evaluation by taste panel. After the completion of sensory evaluation, which took about 30 minutes, the berries remaining in the refrigerator were packed into small aluminum cups and transferred to the Instron machine in an ice chest within 10 minutes.

The Instron measurements were conducted as specified above for the first set of experiments, but the time lag between the end of thawing operation and the beginning of the Instron measurement in the second set of experiments was roughly one hour. Though ten berries from each thawing operation were compressed using the Instron Machine, each thawing operation was replicated so that an average of twenty Instron measurements was calculated and used in this study. The cross-head speed of the Instron was set at 20 cm/minutes, for this value had been found by Vibbert (1976), to enable the Instron simulate as closely as possible, the mechanical conditions prevailing during the initial stage of mastication.

The sensory evaluation was conducted using ten panelists to evaluate subjectively firmness of the blueberries after each thawing operation (which was replicated) on the second set of purchased berries, by cutting with teeth and by pressing between the thumb and a finger. These subjective methods have been described by Finney (1969) to be related to kinesthetic characteristics or texture of foods. Each panelist was supplied with four blueberries for each of the teeth-cutting and finger-pressing evaluations and was told to evaluate the firmness using a nine-point hedonic scale (Amerine et al., 1965) as follows:

Extremely firm	= 9
Very firm	= 8
Moderately firm	= 7
Slightly firm	= 6
Neither firm nor soft	= 5
Slightly soft	= 4
Moderately soft	= 3
Very soft	= 2
Extremely soft	= 1

The samples of instruction and score sheets can be found in the Appendix .

Results were statistically analyzed by one-way analysis of variance (Kramer and Twigg, 1966) for difference between mean scores and significantly different samples identified using Duncan's Multiple Range Test.

Calculations for determining the standard deviation, the regression analyses and the coefficient of correlation were done using the Wang System 2200 A/B (situated in the Department of Agricultural Engineering) manufactured by Wang Laboratories, Inc., Tewksbury, Massachussetts; while the critical values for correlation coefficients were checked up from "Statistical Tables" compiled by Rohlf and Sokal, 1969.

The three-way analysis of variance of the results was calcuated using a pocket calculator and following the method described by Sokal and Rohlf, 1969.

RESULTS AND DISCUSSION

Effect of Factors Studied on Textural Quality

Statistical analysis of the factors studied (viz freezing medium, thawing medium, and temperature of thawing medium), revealed that only the nature of the freezing medium and the interaction between the thawing medium and temperature had significant effects on the Instron-measured firmness of thawed blueberries after 2-3 days of frozen storage (see Tables 1 and 2). The difference between the effects of freezing in propylene glycol solution and air-blast on firmness was highly significant, with higher firmness values being obtained with berries frozen in the glycol solution. The reason for this increase in firmness after thawing might be due to the fact that faster freezing is achieved using propylene glycol solution than air-blast. With rapid freezing, the course of ice crystal formation and growth is altered, thereby resulting in higher firmness values than slow freezing.

Similarly, statistical analysis of the above mentioned factors revealed that only the nature of the thawing medium and the interaction between the thawing medium and temperature had significant effects on the Instron-measured firmness of thawed blueberries after 60-68 days of frozen storage (see Tables 5 and 6). The difference between the effects of thawing in sucrose solution and in air-blast on firmness was highly significant. Frozen blueberries thawed in sucrose solution were found to be consistently firmer (using the Instron) than those thawed in air-blast, but this trend was not observed with the subjective methods of texture evaluation as will be detailed later in this discussion. The reason for this increase in firmness of berries thawed in sucrose solution is not known to the author. Drip loss measurements and changes in berry weight during thawing, which might have offered clues to the reasons for the observed difference in firmness, were not conducted in this experiment.

Effect of Factors Studied on Thawing Rate

The freezing medium, the thawing medium, and the temperature of the thawing medium respectively, along with the interactions between two or all of these three factors, were found to have significant effects on the thawing rate (from 20° to 40°F) obtained when thawing berries which had either been kept in frozen storage for 2-3 days or for 60-68 days (see Tables 3, 4, 7, and 8).

The difference between the effect of freezing in propylene glycol solution and in air-blast on thawing rate was highly significant, with higher thawing rates being obtained with berries that had been frozen in glycol solution. Similarly, the difference between the effect of freezing in sucrose solution and in air-blast on thawing rate was highly significant, with higher thawing rates being obtained with berries that had been frozen in the sucrose solution. These results indicated that immersion freezing produced faster thawing than air-blast freezing under identical frozen storage and thawing procedures.

The results in Tables 3 and 7 on the effect of the thawing medium on thawing rate agree with the statistical analysis in Tables 4 and 8 respectively, which showed that thawing in either of the solutions (propylene glycol and sucrose) produced faster thaw than thawing in air and this could be due to the fact that these thawing solutions have higher convective heat transfer coefficients than air.

Table 1. Means* of Instron measurement (viz compression force in GM) after thawing of blueberries which had been kept in frozen storage at -10°F for 2-3 days.

Freezing medium	Thawing medium	Temperature of the thawing medium		
		80°F	90°F	100°F
Air-blast -40°F/10 min.	Air-blast	255 ± 88	279 ± 92	215 ± 71
	Propylene glycol (50% solution)	290 ± 34	318 ± 67	237 ± 77
50% Propylene glycol solution -20°F/4.5 min.	Air-blast	287 ± 53	304 ± 64	328 ± 62
	Propylene glycol (50% solution)	295 ± 61	319 ± 33	299 ± 51

* (1 compression/berry x 10 berries x 2 replicates thawed; n = 20)

Table 2. 3-way analysis of variance of the main effects and interactions in Table 1.

Source of variation	df	SS	MS	F_s
Total	239	1,131,097		
Replicate	1	992	992	0.23
Freezing medium (F)	1	31,648	31,648	7.41**
Thawing medium (M)	1	141	141	0.03
Temperature of Thawing medium (T)	2	21,940.6	10,970.3	2.57
F x M	1	15	15	.00
F x T	2	6,429.7	3,214.9	0.75
M x T	2	81,568.3	40,784.2	9.54**
F x M x T	2	18,385.0	9,192.5	2.15
Error	227	969,977.1	4,273.03	

** Significant at 1% level.

Table 3. Thawing rates* in °F/min (from 20° to 40°F) of thawed blueberries which had been kept in frozen storage at -10°F for 2-3 days.

Freezing medium	Thawing medium	Temperature of the thawing medium		
		80°F	90°F	100°F
Air-blast -40°F/10 min.	Air-blast	$4.13 \pm 0.87^{+}_{a}$	$5.01 \pm 0.71_{a}$	8.3 ± 0.34
	Propylene glycol (50% solution)	16.88 ± 1.57	33.11 ± 0.22	56.10 ± 0.99
50% Propylene glycol solution -20°F/4.5 min.	Air-blast	$5.39 \pm 1.09_{b}$	$6.57 \pm 0.10_{b}$	9.85 ± 0.72
	Propylene glycol (50% solution)	18.46 ± 2.17	50.92 ± 3.22	58.41 ± 0.74

* (3 berries/experiment x 2 replicates thawed; n = 6)
\+ (Means of thawing rates followed by like letters along the rows in the above Table are not significantly different P ≥ 0.05, Duncan, 1955)

Table 4. 3-way analysis of variance of the main effects and interactions in Table 3.

Source of variation	df	SS	MS	F_s
Total	23	9930.93		
Replicate	1	0.03	0.03	0.01
Freezing medium (F)	1	114.80	114.80	28.42**
Thawing medium (M)	1	6325.48	6325.48	1565.71**
Temperature of Thawing medium (T)	2	1936.27	968.14	239.64**
F x M	1	49.05	49.05	12.14**
F x T	2	85.04	42.52	10.52**
M x T	2	1292.70	646.35	159.99**
F x M x T	2	83.14	41.57	10.29**
Error	11	44.42	4.04	

** Significant at 1% level.

Table 5. Means* of Instron measurement (viz compression force in GM) after thawing of blueberries which had been kept in frozen storage at -10°F for 60-68 days.

Freezing medium	Thawing medium	Temperature of the thawing medium		
		80°F	90°F	100°F
Air-blast -40°F/10 min.	Air-blast	459 ± 60	419 ± 48	448 ± 67
	Sucrose (22.5% solution)	436 ± 72	469 ± 47	479 ± 56
30% Sucrose solution 0°F/4 min.	Air-blast	446 ± 73	436 ± 61	441 ± 60
	Sucrose (22.5% solution)	487 ± 52	514 ± 34	462 ± 77

* (1 compression/berry x 10 berries x 2 replicates thawed; n = 20)

Table 6. 3-way analysis of variance of the main effects and interactions in Table 5.

Source of variation	df	SS	MS	F_s
Total	239	973,219.3		
Replicate	1	2,528.5	2,528.5	0.70
Freezing medium (F)	1	9,337.5	9,337.5	2.59
Thawing medium (M)	1	64,977.5	64,977.5	18.00**
Temperature of Thawing medium (T)	2	244.3	122.1	0.03
F x M	1	11,718	11,718	3.25
F x T	2	19,793	9,896.5	2.74
M x T	2	31,486	15,743	4.36*
F x M x T	2	13,899.8	6,949.9	1.93
Error	227	819,234.8	3,608.9	

* Significant at 5% level.
** Significant at 1% level.

Table 7. Thawing rates* in 0°F/min (from 20° to 40°F) of thawed blueberries which had been kept in frozen storage at -10°F for 60-68 days.

Freezing medium	Thawing medium	Temperature of the thawing medium		
		80°F	90°F	100°F
Air-blast -40°F/10 min.	Air-blast	8.49±0.31	10.73 ±0.22 [+] [a]	10.80±0.25 [a]
	Sucrose (22.5% solution)	24.94±0.24	40.84 ±0.32	55.28±0.40
30% Sucrose solution 0°F/4 min.	Air-blast	6.95±0.20	8.92 ±0.20	10.91±0.22
	Sucrose	35.50±0.29	55.71 ±0.45	68.09±0.50

* (3 berries/experiment x 2 replicates thawed; n = 6)
\+ (Means of thawing rates followed by like letters along the rows in the above Table are not significantly different P ≥ 0.05, Duncan, 1955)

Table 8. 3-way analysis of variance of the main effects and interactions in Table 7.

Source of variation	df	SS	MS	F_s
Total	23	10,491.28		
Replicate	1	0.06	0.06	0.02
Freezing medium (F)	1	121.20	121.20	30.84**
Thawing medium (M)	1	7,270.54	7,270.54	18.50**
Temperature of Thawing medium (T)	2	1,544.41	772.21	196.49**
F x M	1	56.08	56.08	14.27**
F x T	2	87.80	43.90	11.17**
M x T	2	1,282.36	641.18	163.15**
F x M x T	2	85.60	42.80	10.89**
Error	11	43.23	3.93	

** Significant at 1% level.

In both Tables 3 and 7, increasing the temperature of thawing medium from 80° to 100°F led to higher thawing rates. The trend observed showed that increasing the temperature caused increase in the rate of heat transfer and hence, rate of thawing.

These observations made on the effects of thawing medium and thawing temperature on thawing rate support previous observations by Fennema and Powrie (1964) that the rate at which a food material freezes or thaws is influenced by several factors amongst which are the temperature differential between the product and the cooling or heating medium; and also the means of transferring heat energy to, from, and within the the product (conduction, convection and radiation).

Selected thawing curves from which the thawing rates were calculated are illustrated in Figures 1, 2, 3, and 4. The curves are designated by two letters and a number in which the first letter represents the freezing medium (air-blast, 50% by weight propylene glycol solution or 30% by weight sucrose solution) and the second letter represents the thawing medium (air-blast, 50% by weight propylene glycol solution or 22.5% by weight sucrose solution) while the number represents the thawing temperature. It could be observed from these graphs in general, that curves which represent thawing in solutions (viz propylene glycol and sucrose solutions) are steeper in slope than corresponding curves which represent air thawing; i.e. the former yielded faster thawing rates than the latter due to the reason given above.

Effect of Frozen Storage Period on Textural Evaluation

Differences in Instron measurements were observed for thawed blueberries subjected to the same freezing and thawing treatments but different frozen storage periods at -10°F (see Table 9).

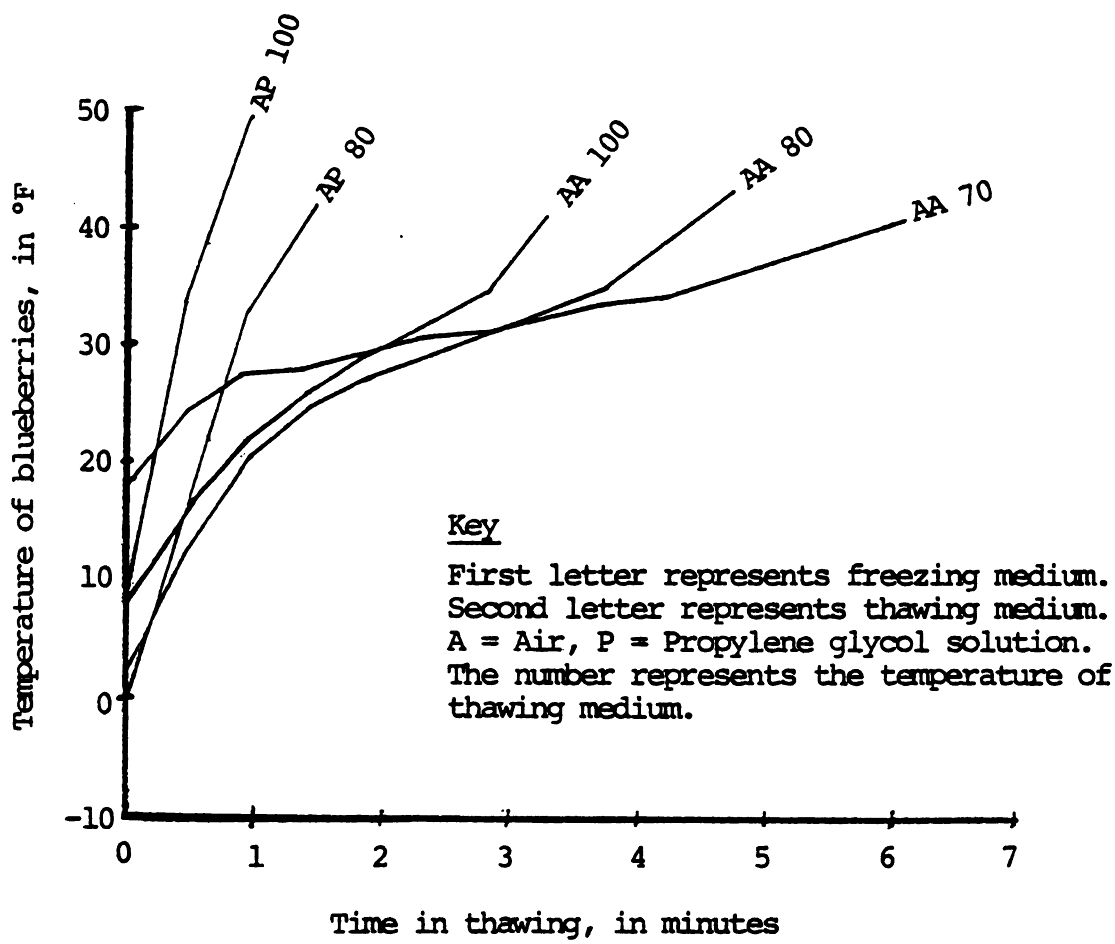

Figure 1. Rate of increase in temperature at the geometric centers of blueberries which had been kept in frozen storage at -10°F for 2-3 days and thawed in both air-blast and propylene glycol solution (50% by weight) at 80°F and 100°F and also in room air at 70°F.

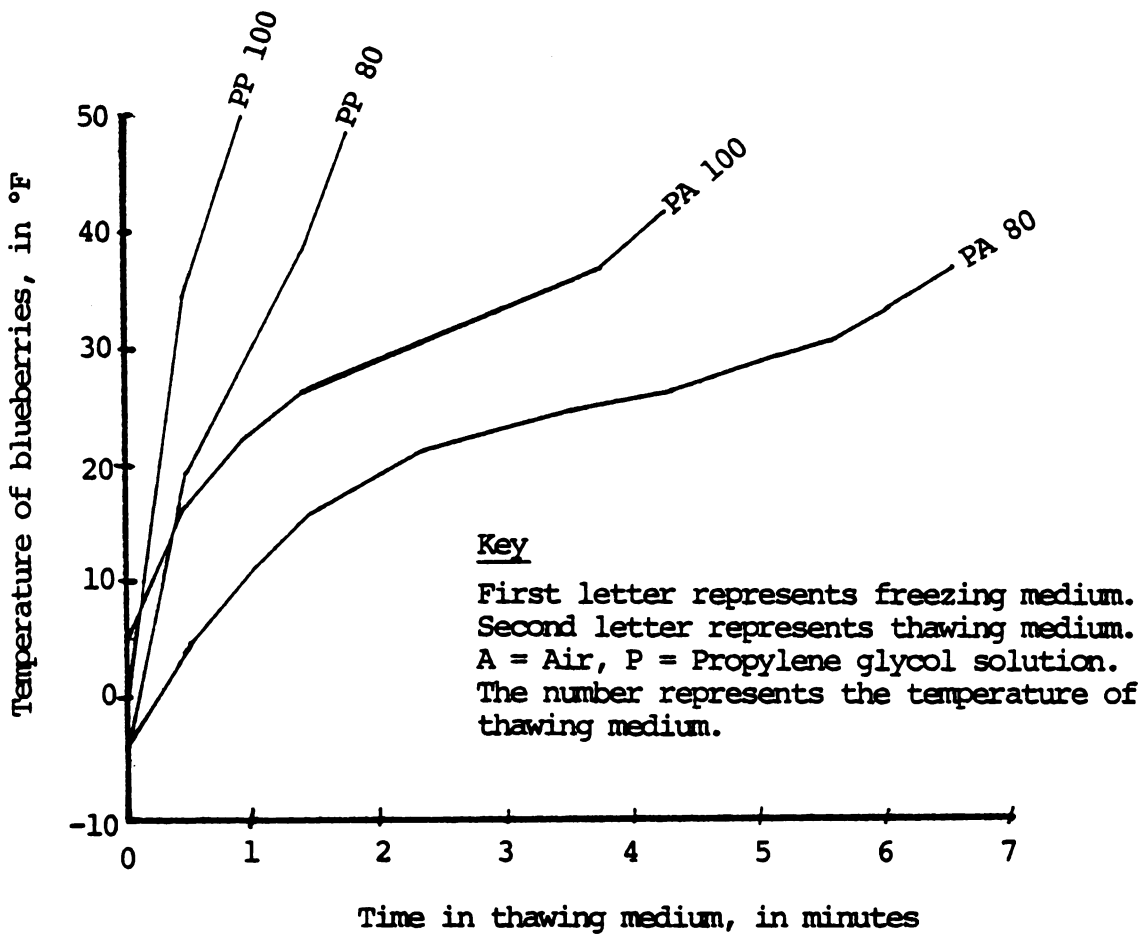

Figure 2. Rate of increase in temperature at the geometric centers of blueberries which had been kept in frozen storage at -10°F for 2-3 days and thawed in both air-blast and propylene glycol solution (50% by weight) at 80°F and 100°F.

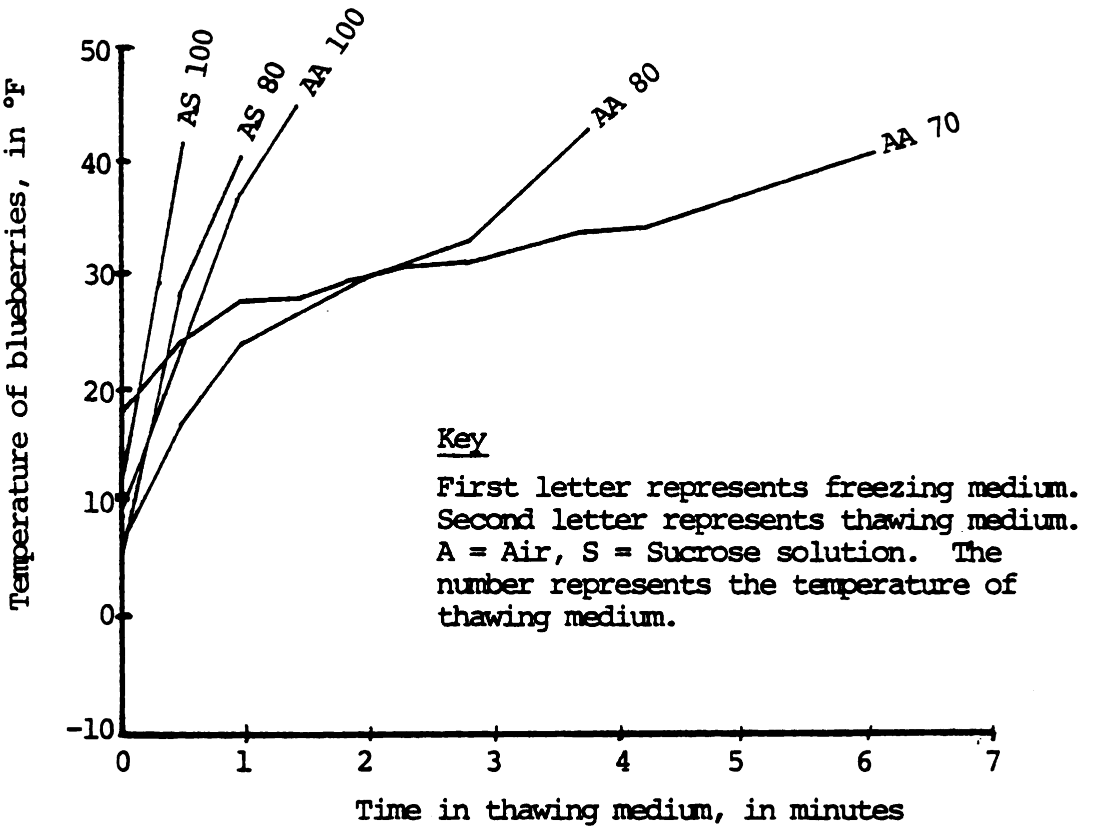

Figure 3. Rate of increase in temperature at the geometric centers of blueberries which had been kept in frozen storage at -10°F for 60-68 days and thawed in both air-blast and sucrose solution (22.5% by weight) at 80°F and 100°F and also in room air at 70°F.

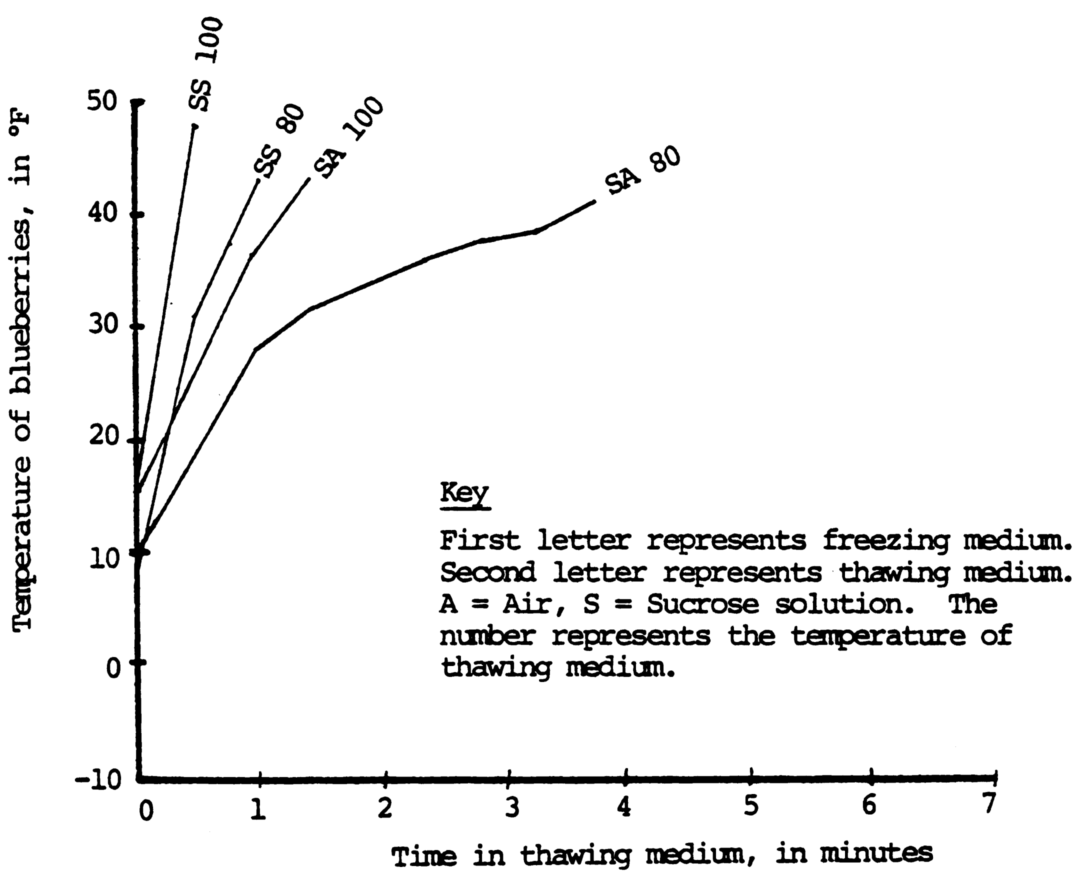

Figure 4. Rate of increase in temperature at the geometric centers of blueberries which had been kept in frozen storage at -10°F for 60-68 days and thawed in both air-blast and sucrose solution (22.5% by weight) at 80°F and 100°F.

Table 9. One-way analysis of variance on the effect of the frozen storage[+] period on the firmness (viz compression force in GM using the Instron) of thawed blueberries.

Treatment imposed on the blueberries	Frozen Storage Period	Means of Instron measurement in gm	F_s
Frozen in air-blast, thawed in air-blast at 80°F	2 - 3 days	255 ± 88	**
	60 - 68 days	459 ± 60	
Frozen in air-blast, thawed in air-blast at 90°F	2 - 3 days	279 ± 92	*
	60 - 68 days	419 ± 48	
Frozen in air-blast, thawed in air-blast at 100°F	2 - 3 days	315 ± 71	**
	60 - 68 days	448 ± 67	

\+ Storage temperature was -10°F
* Significant at 5% level
** Significant at 1% level

Berries stored for 2-3 days had lower Instron values (less firm) than berries stored for 60-68 days. This might have been due to the fact that more dehydration occurred in berries stored for 60-68 days (for some fine ice crystals were observed along the inside walls of the storage tin cans). Dehydration might have become manifested as increase in firmness or Instron measurement, for Karel (1975) remarked that the most common quality defects of dehydrated foods include tough, "woody" texture, slow and incomplete rehydration and loss of juiciness typical of fresh food; and that though the physicochemical basis for these changes is as yet not fully understood, it is thought that in the case of plant materials, loss of cellular integrity and crystallization of polysaccharides such as starch and cellulose is, in fact, promoted by removal of water.

It should be pointed out, however, that berries stored for 2-3 days came from a different batch of raw material than those stored 60-68 days. Textural differences between the two may, therefore, have resulted from raw material differences rather than storage changes.

Objective Versus Subjective Methods of Texture Evaluation

One-way analysis of variance of the data in Table 10 (see Table 11) showed that the objective method employed, viz compression force in gm obtained by using the Instron was very good for it detected differences in means of measurements which are significant at both the 5% and 1% levels of significance, while the subjective methods employed, viz sensory evaluation by taste panel using teeth to cut thawed berries or pressing thawed berries between fingers did not detect differences in firmness to be significant. However, the values obtained (using the

Table 10. Comparative data on firmness (as measured objectively using the Instron* and subjectively+ using a taste panel±) of thawed blueberries which had previously been frozen and kept in frozen storage at -10°F for 60-68 days.

Freezing medium	Thawing medium	Temperature of the thawing medium	Means of firmness measurements: Instron (Compression force in gm)	Taste panel (Cutting with teeth)	Taste panel (Pressing between fingers)
Air-blast -40°F/10 min	Room air	70°F	432 ± 75^{Bb}	2.88 ± 1.73	3.25 ± 1.03
	Refrigerator	42°F	438 ± 88^{Bb}	2.38 ± 0.92	3.25 ± 1.49
	Air-blast	80°F	459 ± 60^{Ab}	3.12 ± 1.51	3.79 ± 1.10
		90°F	419 ± 48^{Bb}	2.35 ± 1.14	3.40 ± 1.29
		100°F	448 ± 67^{Bb}	2.41 ± 1.05	3.50 ± 1.23
	Sucrose (22.5% solution)	80°F	436 ± 72^{Bb}	2.37 ± 1.41	2.34 ± 1.08
		90°F	469 ± 74^{Ab}	2.45 ± 1.18	3.55 ± 1.05
		100°F	479 ± 56^{Aa}	2.34 ± 1.17	3.09 ± 1.45
30% Sucrose solution 0°F/4 min	Air-blast	80°F	446 ± 73^{Bb}	3.34 ± 1.25	3.64 ± 1.52
		90°F	436 ± 61^{Bb}	2.40 ± 1.05	3.15 ± 1.10
		100°F	441 ± 60^{Bb}	2.65 ± 1.29	3.49 ± 1.31
	Sucrose (22.5% solution)	80°F	487 ± 52^{Aa}	2.65 ± 1.12	2.91 ± 1.33
		90°F	5.14 ± 34^{Aa}	1.95 ± 0.75	2.85 ± 1.29
		100°F	462 ± 77^{Ab}	2.21 ± 1.06	2.77 ± 1.40

* (1 compression/berry x 10 berries x 2 replicates thawed; n = 20)

\+ (Use of a nine-point hedonic scale to rate responses of taste panel, viz extremely firm = 9, extremely soft = 1)

± (10 panelists/taste panel x 2 replicates thawed; n = 20)

++ (Means followed by big like letters are not significantly different, $P \geq 0.05$, while means followed by small like letters are not significantly different $P \geq 0.01$, Duncan, 1955)

Table 11. One-way analysis of variance of the means of firmness (as measured objectively using the Instron and subjectively using a taste panel) of thawed blueberries after 60-68 days of frozen storage at -10°F.

Method used in measuring firmness	F_s
Instron (compression force in gm) measurements	**
Taste panel (cutting with teeth) ratings	ns
Taste panel (pressing between fingers) ratings	ns

** Significant at 1% level

hedonic rating scale) for finger-pressing were, in the majority, found to be consistently higher than the corresponding values obtained for cutting of thawed berries by teeth.

The one-way analysis of variance also showed that the means of firmness measurements using the Instron, for berries thawed in room air and refrigerator fitted into the second group of thawed berries that were less firm.

The values obtained for the coefficients of correlation between the objective and subjective methods of texture evaluation were significant at the 5% level when frozen blueberries were thawed in air-blast but were not significant when berries were thawed in sucrose solution (see Table 12). The degree of correlation between the Instron measurements and finger-pressing evaluation of air-thawed berries was found to be higher than that between the Instron measurements and teeth-cutting evaluation of the air-thawed berries. This might have been due to the fact that the finger-pressing method was more similar to the mode of operation of the Instron in that both measured compression forces only; while the teeth-cutting method was not able to detect firmness alone for several complex sensations had been found to be involved in oral evaluation of foods.

It could also be seen in Table 12 that the coefficient of correlation between the two subjective methods of texture evaluation (viz teeth-cutting and finger-pressing) is only significant for blueberries thawed in air-blast only.

The relationship between Instron measurements and thawing rates (in Tables 1, 3, 5, and 7) was analyzed using linear, Nth order, geometric and exponential regressions. Only the Nth order regression

Table 12. Correlation coefficients between the means+ of objective and subjective firmness measurements on thawed blueberries after a frozen storage period of 60-68 days at -10°F.

Pair of means of firmness being correlated	Coeff. of Determination	Coeff. of Correlation	Standard error of estimate
Instron vs. teeth-cutting for both air- and sucrose-thawing	0.101	0.286(ns)	0.383
Instron vs. teeth-cutting for only air-thawing	0.40	0.641(*)	0.365
Instron vs. teeth-cutting for only sucrose-thawing	0.142	0.377(ns)	0.244
Instron vs. finger-pressing for both air- and sucrose-thawing	0.072	0.229(ns)	0.438
Instron vs. finger-pressing for only air-thawing	0.470	0.686(*)	0.177
Instron vs. finger-pressing for only sucrose-thawing	0.127	0.357(ns)	0.415
Teeth-cutting vs. finger pressing for both air- and sucrose-thawing	0.338	0.581(ns)	0.431
Teeth-cutting vs. finger-pressing for only air-thawing	0.463	0.681(*)	0.311
Teeth-cutting vs. finger-pressing for only sucrose-thawing	0.045	0.214(ns)	0.477

+ The means of firmness measurements used in calculating the correlation coefficients are based upon the data in Table 10.

* Significant at 5% level.

analysis was reported (see Table 13) for it was the only analysis that gave significant results at the 5% level, for thawed blueberries which had been kept in frozen storage at -10°F for 60-68 days. This Nth order regression analysis revealed that the following equation (using the data in Table 13) illustrates the relationship between texture evaluation (represented by Y) in gm compression force using the Instron and thawing rate in °F/minute (represented by X):

$$Y = 421.84 + 2.09X - 0.02X^2.$$

Table 13. Nth order regression analysis of the relationship between Instron measurement+ (viz compression force in GM) and thawing rates+ in °F/min of thawed blueberries

Regression data	Frozen storage period at -10°F	
	2 - 3 days	60 - 68 days
0 Deg. Coefficient	270.44	421.84
1 Deg. Coefficient	3.62	2.09
2 Deg. Coefficient	-6.13	-0.02
F_s (Regression Table)	ns	*
Coeff. of Determination	0.30	0.54
Coeff. of Correlation	0.55 (ns)	0.74 (*)
Standard error of estimate	25.77	19.60

* Significant at 5% level

+ The means of Instron measurement and thawing rates used in this analysis are based upon the data in Tables 1, 3, 5, and 7.

CONCLUSIONS

Blueberries which had been hand-harvested at DeGrandchamp, South Haven, Michigan, were frozen, stored and thawed using various methods, and subsequently evaluated (using both objective and subjective methods of measurement) for textural quality.

It was found that only the freezing medium amongst the factors studied, within the ranges and under the conditions that were tried, had a significant effect upon the final texture of the thawed blueberries after 2-3 days of frozen storage. It was also found that only the thawing medium had a significant effect upon the final texture of thawed blueberries after 60-68 days of frozen storage.

Differences in Instron-measured firmness due to the interaction between the thawing medium and temperature of thawing medium indicated that the relationship between these two factors was not constant, but instead, varied with the test conditions that were used.

All the variations in the factors studied, however, exhibited significant effects on the thawing rates. For instance, differences in thawing rate were associated with differences in freezing medium, thawing medium, and temperature of thawing medium regardless of the period of frozen storage. Differences in thawing rate due to the interaction between two or all of the three factors mentioned above indicated that the relationships between these factors were not constant, but instead, varied with the test conditions that were used.

Generally, faster thawing rates were obtained for the blueberries frozen in liquid media than in air-blast. Faster thawing rates were also obtained for the blueberries thawed in liquid media than in air-blast. Faster thawing rates were also obtained for the blueberries thawed in liquid media than in air-blast and this was attributed to the fact that liquid media have higher convective heat transfer coefficients than air. Increasing the thawing temperature from 80° to 100°F also led to higher thawing rates due to increase in the rate of heat transfer with increase in temperature.

Under the test conditions used, the objective method (Instron measurement) was more reliable for evaluating texture of thawed blueberries than any of the subjective methods, viz sensory evaluation (cutting with teeth and pressing with fingers) by taste panel. The objective method detected significant differences in means of measurements at the 1% level of significance, while the latter subjective methods did not detect any significant difference in the firmness of the thawed berries. Of the two subjective methods studied, the finger-pressing method consistently gave higher values of firmness measurement using the hedonic rating scale, than the teeth-cutting method.

Though the correlation coefficients for objective versus sensory methods of texture evaluation were significant at the 5% level for berries thawed in air-blast, the values were relatively low and, consequently, did not indicate very good correlation between objective and sensory methods. The coefficient of correlation between the two subjective methods of texture evaluation was found to be significant only for blueberries thawed in air-blast.

When subjected to an Nth order regression analysis, the relationship between Instron measurements (Y) and thawing rates (X) was found to be significant at the 5% level, but only for those berries that had been stored for 60-68 days. The Nth order analysis indicated that the relationship could be expressed using a second order polynomial, viz $Y = 421.84 + 2.09X - 0.02X^2$.

SUGGESTIONS FOR FURTHER STUDY

1. Investigating if a change in the weight per berry occurs when frozen blueberries are subjected to a thawing method, and the possible effect of a change in weight on texture measurement.
2. Investigating in a greater detail than was done in this study; thawing of frozen blueberries in air-blast, for this medium would hopefully facilitate better the measurements of drip loss and weight change than a liquid medium such as propylene glycol or sucrose solution.
3. Determination of the part of the thawing regime which mostly limits textural quality of blueberries when thawed in still air at room temperature; for this portion of the thawing curve, if it can be detected would represent the critical area that needs to be more closely studied in order to alleviate deterioration in textural quality of frozen and thawed blueberries.

APPENDIX

Michigan State University - Fruits Laboratory (Firmness test)

Directions: Please analyze sample provided for firmness by pression each fruit between the thumb and fingers until it ruptures.

Name: ______________________ Plate No. ________ Date _______

Code ________	Code ________	Code ________	Code ________
___ Extremely firm	___ Extremely firm	___ Extremely firm	___ Extremely firm
___ Very firm	___ Very firm	___ Very firm	___ Very firm
___ Moderately firm	___ Moderately firm	___ Moderately firm	___ Moderately firm
___ Slightly firm	___ Slightly firm	___ Slightly firm	___ Slightly firm
___ Neither firm nor soft	___ Neither firm nor soft	___ Neither firm nor soft	___ Neither firm nor soft
___ Slightly soft	___ Slightly soft	___ Slightly soft	___ Slightly soft
___ Moderately soft	___ Moderately soft	___ Moderately soft	___ Moderately soft
___ Very soft	___ Very soft	___ Very soft	___ Very soft
___ Extremely soft	___ Extremely soft	___ Extremely soft	___ Extremely soft
Comments	Comments	Comments	Comments

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