EFFECT OF SELECTED FREEZING METHODS AND SELECTED ADDITIVES ON THE QUALITY CHARACTERISTICS OF FROZEN SLICED BANANAS

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ABSTRACT

EFFECT OF SELECTED FREEZING METHODS
AND SELECTED ADDITIVES ON THE
QUALITY CHARACTERISTICS OF
FROZEN SLICED BANANAS

by Anne Ing-Chung Chen

This investigation was initiated to determine the effect of freezing methods in combination with syrup concentration on the quality characteristics of banana slices. The study also investigated the effect of $CaCl_2$ on the textural qualities of sliced bananas and the effect of an ascorbic acid/citric acid mixture (ACM) in maintaining color of IQF banana slices. Sensory evaluations, objective measurements and chemical tests were used to evaluate the three replications of each variable of banana slices and the data were statistically analyzed.

Sensory evaluation of banana slices indicated that the visually-judged texture ("visual texture"), color, mouth feel, flavor and clarity of syrup for fresh banana slices scored significantly higher than either frozen or frozen-stored banana slices. The color of banana slices in syrup scored significantly higher than that of IQF slices while the visual texture and clarity of syrup for slices in 40% syrups were scored higher than that of slices in 20% syrup.

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Anne Ing-Chung Chen

The Hunter color-difference meter was used to determine the lightness (L), redness (a_L) and yellowness (b_L) of banana slices. Fresh slices were lighter and more yellow than frozen or frozen-stored banana slices. Both L and b_L values correlated significantly with sensory scores for color. The frozen-stored banana slices were significantly redder than either fresh or frozen slices and negatively correlated with sensory scores for color.

The Allo-Kramer shear press used to determine the texture of banana slices indicated that fresh banana slices were firmer than frozen or frozen-stored slices. The IQF slices were firmer than the slices packed in syrups. There were significant correlations between shear press measurements and both visual texture and mouth feel as evaluated by the taste panel.

The analyses for total ascorbic acid retention showed that both frozen and frozen-stored banana slices had a higher content than fresh banana slices. The IQF slices with the regular amount of ACM in the syrup contained less total ascorbic acid than the other variables.

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By

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INTRODUCTION

Bananas are one of the best known fruits throughout the world. Production of the extremely perishable fruit is characterized by rapid growth and quick financial returns on capital outlay. Economic losses result when bananas are not consumed within a short time after harvest (Simmonds, 1966).

Total banana production is estimated to be about 20 million tons per year. Most countries with climatic conditions suited for banana production export part of their crop. From Taiwan, bananas entering into international trade, are sold to Japan (Simmonds, 1966). However, more bananas are produced during the two growing seasons in Taiwan than are traded or consumed locally resulting in economic losses. By preservation of the bananas the consumption period would be extended thus averting economic losses.

Attempts to satisfactorily freeze bananas have met with partial success in that bananas may be frozen for ice cream or bakery trade. While very limited data are available, inherent problems in freezing the fruit are textural changes, browning and loss of flavor. Use of sucrose in combination with ascorbic acid reportedly is helpful in retarding these changes (Von Loesecke, 1949). A 40% syrup or less has been recommended for maximum quality retention (Meyer, 1964). However, Guadagni (1969) suggested consumers will have to accept the frozen fro

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fruit with less than an ideal texture.

Calcium chloride ($CaCl_2$) has been added to tomatoes during the canning process to avert tissue breakdown. The essential reaction appears to be the formation of calcium pectate by interaction of the calcium ions with pectic acid (Loconti *et al.*, 1941). The effect of $CaCl_2$ on banana slices has not been investigated.

Conflicting reports appear in the literature on the ascorbic acid content of bananas (Miller *et al.*, 1945; Von Loesecke, 1949). In a recent study, Wenkam *et al.* (1965) reported the ascorbic acid content of bananas was 6 mg/100 g of fruit. The effect of freezing on the ascorbic acid content of bananas has not been investigated.

The primary purpose of this study was to investigate the effect of freezing method and subsequent storage as well as sucrose concentration in combination with ascorbic acid on the quality characteristics and the ascorbic acid content of frozen sliced bananas. To study the effect of freezing method, sliced bananas were frozen in syrup and individually quick frozen (IQF) after dipping in 40% syrup containing two levels of ascorbic acid. For bananas frozen in syrup, sucrose concentrations of 20 and 40% were used, each containing one level of ascorbic acid.

A secondary purpose of this study was to investigate the feasibility of using $CaCl_2$ to improve the textural quality of frozen banana slices. Hence, $CaCl_2$ was added to syrups containing 20 and 40% sucrose before sliced bananas were frozen in the mixture. These banana slices were compared with those frozen in syrups of the same concentration with no added $CaCl_2$.

To determine the effect of the freezing and/or thawing process *per se*, the quality characteristics of banana slices were investigated prior to and after two to three weeks of frozen storage. The effect of a three-month storage period was also determined.

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REVIEW OF LITERATURE

Composition of Plant Tissue

Plant parts used as food are composed of tissues which in turn are composed of many different types of cells, each of which may be peculiar to a specific tissue. Cellular contents vary greatly among varieties of plant tissues. The physical and chemical composition of plant tissue will be discussed in general and then specifically as related to bananas.

Physical composition

Plant tissue is composed of living cells capable of undergoing metabolic reactions after harvest. The chief type of cell in the edible portion of most fruits is the parenchyma cell. The thin, cellulose walls of parenchyma cells in the young plant may be separated by air spaces or held together by pectic cementing substances. As the plant ages, the cell walls may increase in thickness and the nature of the cementing substances may change (Meyer, 1960).

The protoplasm of parenchyma cells contains many different molecules, forming either a viscous fluid or a gel. The protoplasm is differentiated into various cell parts such as the nucleus, cytoplasm, plastids and vacuoles. The nucleus directs the activity of the cell while the cyt

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cytoplasm, an undifferentiated part of the protoplasm, surrounds the nucleus and forms a rather thin layer within the cell wall (Griswold, 1962). Plastids, contained in the cytoplasm, may be chloroplasts or green pigments, chromoplasts or pigments other than green, and/or leucoplasts which produce and store starch. Vacuoles, often referred to as cell sap, are made up of droplets of solutions with strands of cytoplasm around them (Meyer, 1960).

In addition to parenchyma cells, conducting, supporting and protective cells are also present in plant tissue. Conducting cells of two types, xylem and phloem, are composed of long tubes through which food is distributed to the plant. Supporting cells, although not generally numerous in plants desirable for food, are long pointed cells with walls of cellulose and lignin or pectic substances. Protective cells or specialized parenchyma cells that secrete cutin or contain suberin, are closely pressed together and are usually quite tough. The protective cells provide the plant with minute valves through which exchange of gases can occur; however, the coating of cutin or suberin is insoluble in water.

Slocum (1933), as cited by Von Loesecke (1949), has detailed the morphology of the banana with particular emphasis on the skin of the fruit. In another treatise, as cited by Von Loesecke (1949), Wolfson studied the morphology of the banana fruit or pulp. According to his report, the cells of the center of the green banana fruit are long and boxlike in shape containing in addition to the cytoplasm and nuclei, numerous starch grains. The banana pulp contains few or no intercellular spaces and the cells adhere firmly to one another. As the fruit ripens, the starch tends to disappear. Tissues of the outer portion of

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of the pulp show cells of different shapes, held together by pectic substances.

Latex tubes, as found in banana skins, are also present in the pulp outlining the margin of the individual carpels. The watery fluid found in the latex tubes is white and milky in appearance. It possesses a pronounced astringent taste and will turn brown in the presence of air because of the tannins present (Von Loesecke, 1949).

Chemical composition

Fruits vary greatly in chemical composition; however, they are generally high in water and relatively low in protein. Carbohydrates are present as cellulose, pectic substances, sugars such as fructose, glucose and sucrose, and starch, although the starch tends to disappear on ripening. The vitamin and mineral content is specific to the kind of fruit (Meyer, 1960; Griswold, 1962). Organic acids, aldehydes, alcohols, esters, tannins and similar compounds are also present in fruits (Griswold, 1962).

Data on the composition of ripe banana pulp are presented in Table 1. The fruit is composed mainly of water and carbohydrates and has negligible amounts of protein and fat.

Tannins

The darkening reaction on the exposure of banana tissue to air is a result of oxidation of phenolic substances. Tannins are phenolics with molecules large enough to complex with and precipitate proteins, a property responsible for the astringent flavor imparted to many fruits.

Table 1. --Composition of banana, per 100 g of edible portion.[a]

Fruit	Moisture (%)	Food Energy (Calories)	Protein (g)	Fat (g)	Total Carbo-hydrate (g)	Fiber (g)	Ash (g)	Calcium (mg)	Phosphorus (mg)	Iron (mg)	Vitamin A Value (microgram)	Thiamine (mg)	Riboflavin (mg)	Niacin (mg)	Ascorbic Acid (mg)
Dessert															
Bluefields (Gros Michel)	71.05	102	1.46	0.22	26.47	0.57	0.80	4.4	23.1	0.27	172[b]	0.030	0.044	0.70	6
Brazilian ("Apple")	66.94	118	0.87	0.36	31.07	0.68	0.76	7.0	30.4	0.28	158	0.041	0.076	0.59	14.6
Chinese (Cavendish)	79.22	72	1.75	0.18	18.03	0.25	0.82	2.0	13.4	0.35	82[b]	0.026	0.041	0.61	8
Lacatan	63.09	130	1.19	0.18	34.55	0.31	0.99	6.6	22.5	0.30	77	-----[c]	-----[c]	----[c]	9.6
Williams Hybrid	71.33	100	1.08	0.13	26.56	0.11	0.90	5.0	17.5	0.49	88	0.044	0.045	0.69	5.1
Plantain (cooking)															
Largo	64.05	127	1.28	0.30	33.50	0.43	0.87	4.3	20.5	0.54	273	0.038	0.064	0.43	17.5
Maiamaoli	67.17	115	0.93	0.04	30.87	0.31	0.99	3.7	26.3	0.45	388	0.054	0.119	0.65	15.2
Popoulu	67.40	114	1.16	0.04	30.36	0.33	1.04	1.2	26.0	0.30	711	0.060	0.071	0.66	14.5

[a]Wenkam et al., 1965.

[b]Moisture content not determined, but assumed to be similar to value given in moisture column.

[c]" ----" indicates that no determinations were made.

As indicated above, tannins are present in the latex tubes of banana skins and fruit.

Tannins have been reported as diminishing as the banana ripens. Barnell et al. (1945) reported the tannin fraction of the green fruit diminished to about one-fifth of its value when the fruit ripened as studied by diastase inactivation. In contradiction, Harris et al. (1937) stated that the total amount of tannins remained constant during ripening; however, their state changed to an insoluble, inert "vegetative tannate".

Barnell et al. (1945) studied the phenolic compounds in bananas. The compounds, leucoanthocyanin, leucodelphinidin, and leucocyanidin, were identified as present in the banana fruit.

The compound, 3,4-dihydroxyphenylethylamine, is also present abundantly in the skin of bananas but relatively sparse in the pulp (Simmonds, 1966). This compound is the principal substrate of banana polyphenoloxidase and thus responsible for the blackening of damaged fruit (Griffiths, 1959).

Other substances, 5-hydroxytryptamine, norepinephrine and tyramine, have been detected in banana fruit (Udenfriend et al., 1959). There is little information regarding their behavior during ripening but 5-hydroxytryptamine appears to be present in fairly constant amounts in the banana pulp and in increasing amounts in the skin.

Enzymes. Studies on the enzyme content of bananas have been reviewed by Von Loesecke (1949). Onslow (1920) made a systematic investigation of many fruits and classified them into two groups, 1) those containing catechol substances and oxygenase and 2) those lacking in these two substances. According to her report, bananas belong to the first group. However, more rec

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recent investigations have shown that peroxidase and catalase are always present in both classifications while oxygenase is absent in the second classification (Braverman, 1963). More recently, the name oxygenase is no longer used; instead, phenolase, polyphenolase and polyphenol oxidase are applied.

Onslow (1920) reported the oxygenase, as present in both the skin and the banana fruit, catalyzes the oxidation of catechol. In addition, the oxygenase of the skin activated the oxidation of certain aromatic compounds. Phenol oxidases catalyze the aerobic oxidation of certain phenolic substrates to quinones and cause the browning of plant tissues (Palmer, 1963). Its effect on quality has been concentrated on color changes and oxidation of Vitamin C. Joslyn et al. (1951) stated that not only the phenol oxidase, but the cytochrome oxidase was also the primary browning agent of fruit.

Yasunobu (1959), as cited by Palmer (1963) stated that phenol oxidases catalyze the oxidation of a wide variety of substrates, but each individual enzyme tends to catalyze the oxidation of one particular phenol more readily than others. Polyphenoloxidase with optimum pH 7, which has been shown to occur in the pulp and peel of the banana fruit, follows this general pattern. Palmer (1963) reported that dopamine (3,4-dihydroxyphenylethylamine) is the only significant substrate in the browning reaction of the banana fruit.

Peroxidase has been widely used as an index of enzyme activity in plant tissue because of its high resistance to thermal inactivation (Aylward et al., 1969). This enzyme catalyzes the oxidation of certain phenolic or aromatic amine compounds to form dark colored polymers. Balls et al.

(1935) indicated that peroxidase was responsible for darkening of injured apple tissue. Ponting *et al*. (1948), however, demonstrated that peroxidase catalyzed darkening of apple tissue was responsible for only a small portion of the color changes. In addition, peroxidase has been recognized as the off-flavor causing enzyme (Aylward *et al*., 1969).

Vitamin content

In a review of the vitamin content of bananas, Simmonds (1966) cited literature showing the following vitamins were contained in the fruit; B-carotene, thiamine, riboflavin, pyridoxine, niacin, pantothenic acid, inositol, folic acid and ascorbic acid. Banana varieties show considerable variance in vitamin content. For example, Rudra (1936) found that the pulp of the plantain contained nine times as much ascorbic acid as the pulp of the banana.

Miller *et al*. (1945) stated that the two most widely grown varieties of bananas, Bluefield and Chinese, were only fair sources of Vitamin A, contained negligible amounts of thiamine and were poor sources of ascorbic acid. These workers also reported the cooking banana, Maiamaoli, was a good source of Vitamin A, a poor source of thiamine and a fair source of ascorbic acid. While Harris *et al*. (1939) stated that bananas were a good source of Vitamin C, they also reported that the fruit lost some of its ascorbic acid by exposure to air during the preparation process of slicing.

Bananas have been investigated by many workers for ascorbic acid content and different results have been reported. Table 2 summarizes the findings of these investigators. Whenever possible, the variety of

Table 2. --Ascorbic acid content of bananas as determined by various investigators.[a]

Investigator	Ascorbic Acid mg/g of Pulp
Givens et al.[b]	0.05
Eddy and Kellogg[c]	0.10
Eddy[d]	0.05
Dalldorf[e]	0.05
Birch et al.[f]	0.15
Leverton[g] (Honduras grown)	0.073
Harris and Poland[h]	0.10
Harris and Poland[i] (Gros Michel)	0.053-0.111
Thornton[j] (Gros Michel)	0.10
Munsell[k] (Gigante, Spanish)	0.068-0.071
Rose[l]	0.085-0.12

[a]Adapted from Von Loesecke, H. W. (1949).

[b]Givens, M. H., Cluggage, H. B., and Van Horne, E.G., Proc. Soc. Exptl. Biol. Med., 18, 140 (1921).

[c]Eddy, W. H., and Kellogg, M., Am. J. Public Health, 17, 27 (1927).

[d]Eddy, W. H., Am. J. Public Health, 19, 1309 (1929).

[e]Dalldorf, G., J. Exptl. Med., 53, 289 (1931).

[f]Birch, T. W., Harris, L. J., and Ray, S. N., Biochem. J., 27, 590 (1933).

[g]Leverton, R. M., Food Research, 2, 59 (1937).

[h]Harris, P. L., and Poland, G. L., ibid., 2, 311 (1937).

[i]Harris, P. L., and Poland, G. L., ibid., 4, 317 (1939).

[j]Thornton, N. C., Contrib. Boyce Thompson Inst., 13, 201 (1943).

[k]Munsell, H. E., Food Research, 10, 42 (1945).

[l]Rose, M. S., Foundations of Nutrition, Macmillan, New York, 1933.

banana is indicated.

Thornton (1943) showed that ascorbic acid increased slightly at the time of early development of the yellow color of bananas. The ascorbic acid content fell gradually with complete yellowing to 10 to 12 mg/100g of pulp. According to his report, the ascorbic acid content remained at this level until more than 50% of the peel had turned brown during normal ripening and the pulp had softened. Further reduction in the ascorbic acid content took place with continued ripening.

Harris _et al_. (1939) found that slight chilling had no deleterious effect on the ascorbic acid content of the fruit. However, severe chilling as indicated by blackened skin, resulted in losses of over 50% of the ascorbic acid.

In addition to the vitamin content, bananas have been reported to be a fair source of calcium and iron. In addition, they contain copper, iodine, manganese, zinc, cobalt, potassium, magnesium, sodium and phosphorus (Bogert, 1942).

Methods of Processing Bananas

Bananas have been processed by canning, dehydration and freezing. In addition, numerous speciality products such as powder, flour, jam and paste have been tried; however, bananas lose much of their flavor in development of these items and these various products have not been readily acceptable.

Canning

According to Von Loesecke (1949), bananas should be processed under pressure because of the high pH of the fruit; however, processing under pressure ruins the flavor and significantly alters the texture of the bananas. The author suggested combining banana slices with citrus juice or with citrus fruits such as grapefruit, tangerines or oranges to alter the pH for processing.

Simmonds (1966) pointed out that canning is not a satisfactory processing method for bananas because of their pH. However, United Fruit Company have in pilot production, canned bananas in sucrose syrup (Lawler, 1967).

Lynch *et al*. (1959) outlined a procedure for canning bananas. The banana slices were packed with a 30^{o} Brix syrup containing 0.5% citric acid and 0.2% $CaCl_2$. Quality of the bananas was not reported.

Dehydration

Banana flour has been manufactured from unripe fruit and banana powder produced from ripe fruit. In addition, dehydrated banana slices have been processed (Brekke *et al*., 1967).

Generally, banana powder is made by passing the peeled fruit through a meat chopper to obtain a slurry which may be dried on a steam-heated drum dryer. Double drums are preferable for the processing and the distance between the drums must be carefully adjusted to variations in the ripeness of the fruit to avoid excessive crumbling. The product, as it comes from the drums, is in the form of flakes which may or may not be ground. The flavor of drum-dried flakes or powder is that of cooked bananas; hence, the product provides a high quality ingredient in cooked or baked products.

Brekke et al. (1967) reported that banana slices were dehydrated by air-blast drying, drum drying and freeze drying. Sulfur dioxide treatment prior to drying was used for comparison. They found the treatment with SO_2 improved the product in all of these drying methods. Upon reconstitution, the freeze-dried slices more nearly resembled fresh banana slices than did slices dried by the other methods. Stability of the products showed the air-blast dried banana slices the least stable, drum-dried better and freeze-dried the best.

Freezing

Meyer (1964) outlined a procedure for home freezing of mashed bananas. Working rapidly, banana slices were mashed, combined with a mixture of sugar and ascorbic acid-citric acid powder, packaged and then frozen. The author recommended defrosting only until soft enough to combine with other ingredients used in preparation of a food item. Procedures for freezing sliced bananas have also been outlined (Harding, 1951).

Von Loesecke (1949) stated that unlike many other fruits, bananas d

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do not seem to be well adapted for preservation by freezing. The defrosted product becomes a soggy mass, rapidly darkens and there is a loss of flavor. Darkening and flavor loss are probably due to enzymatic action which is apparent even during frozen storage. He suggested the use of ascorbic acid in combination with citric acid to retard the darkening and loss of flavor. The addition of citric acid probably changes the pH, renders the enzymes inactive and permits the ascorbic acid to act as an antioxidant. Sucrose is used in combination with ascorbic acid and citric acid and is helpful in retarding deteriorative changes.

Freezing Injury of Plant Tissue

Any food may be considered as a system. The specific arrangement of constituents and phases in a food system is responsible for well-defined sensory, physical and chemical properties. Any alteration in the arrangement of components will lead to changes in the characteristics of the entire system.

Physical changes

For frozen pieces of fruit, the most serious consequence of the freezing process is the adverse effect on textural and structural properties (Guadagni, 1969). According to Fennema _et al_. (1964), damage which occurs during freezing is caused by the transformation of water to ice. The expansion of water as it freezes, coupled with the contraction of most nonaqueous constituents of the fruit, results in localized stress which produces physical damage in cellular materials. Materials containing large amounts of water and few intercellular air spaces will show a net expansion upon freezing and hence, a greater likelihood of damage (MacArthur, 1948; Dietrich et al., 1957; Borgstrom, 1961; Joslyn et al., 1952).

Flabbiness of thawed young stems may be due to lack of complete reabsorption of water which migrated from cells to intercellular spaces. Polysaccharides of cell walls are highly hydrophilic and water is abundant in cell walls. Ice crystals may be formed and can easily distort well organized cell wall fibrils and thawed walls may consequently lack rigidity (Fennema et al., 1964).

According to Reeve (1970), certain aspects of freezing damage and its effects on textural qualities are closely related to the structural differentiation of specialized tissues. Fibrous tissues, such as vascular bundles or other thick walled tissues, are resistant to freezing damage. Localized differential rate of freezing often result in torn parenchyma cell walls and the development of large voids. But they seldom produce a comparable damage in the compact, thick-walled tissues. The abnormal softness of mushiness is developed with the freezing and thawing of parenchyma tissue.

According to Levitt (1960), freezing injury is due in all cases to breaks in protoplasmic bonds as a result of local stresses arising on ice formation in tissue. The stresses arise by direct pressure due to ice formation, by ice formed within the cells, and by collapse and subsequent expansion of cells due to dehydration accompanying extracellular ice formation and rehydration on thawing.

Rapid thawing has been claimed to reduce opportunities for product damage. During thawing, however, temperatures rise very rapidly to the melting plateau and remain near the freezing point for a long period of time. According to Fennema et al. (1964), recrystallization may occur during this time.

Effect of freezing temperature. Very rapid freezing has been claimed to improve the texture of frozen peaches and strawberries (Guadagni, 1969). However, Lee et al. (1949) reported that strawberries, raspberries and sliced peaches packed in syrup showed few differences in vitamin content, appearance, flavor and texture whether frozen very slowly, very rapidly or at intermediate rates. According to their report, the retention of these quality factors during a 6-mo storage period at -18°C, recrystallization had occurred to the extent that all samples contained crystals of essentially the same size.

Ice crystals generally have a tendency to enlarge during frozen storage and early stages of thawing. If thawed following minimal storage, rapidly frozen samples will generally exhibit less loss of fluid than slowly frozen samples (Fennema et al., 1964).

Chemical changes

Because metabolic processes continue during storage of fruits, deteriorative changes will depend to a large extent upon the temperature (Fennema et al., 1964). Some typical chemical changes occurring during frozen storage relate to vitamin content (Cain, 1967), color and flavor characteristics (Dietrich et al., 1960; Boggs et al., 1960).

Vitamins. Cain (1967) reported that freezing per se does not injure vitamins. Rather, it is the mishandling both before and after freezing which is responsible for vitamin losses. Particularly destructive to vitamins, is alternation of freezing and thawing during storage. In add

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addition, packaging characteristics such as light transmission, oxygen permeability and water vapor permeability, have effects on the loss of vitamins in foods.

According to Jansen (1969), the loss of and change in different vitamins during the preparation, freezing and storage of foods varies greatly. For example, the Vitamin C content of vegetables is quite labile whereas that in cans of frozen orange juice concentrate is stable.

Cain (1967), in a review of the effect of processing on water-soluble vitamins, reported that the retention of ascorbic acid, thiamine and pantothenic acid was little affected by the time but very much influenced by the temperature of storage. For example, Davis (1956) reported that losses up to 95% of the initial ascorbic acid could be expected in frozen vegetables held for 12 mo. at -12°C. At a storage temperature of -18°C the loss was about 25% while at temperatures of -29°C, the loss was about 5%.

According to Cain (1967) the time of storage was a much more significant factor than temperature of storage in the retention of niacin. Also, increasing the storage temperature had less effect on riboflavin than on ascorbic acid or thiamine retention.

Lee _et al_. (1949) reported that very slow, very rapid and intermediate rates of freezing did not result in marked differences in vitamin content and in retention of vitamins during a 6-mo storage period at -18°C for strawberries, raspberries and sliced peaches.

Harris _et al_. (1939) stated that slight chilling of bananas resulted in no loss of ascorbic acid. However, a loss of more than 50% of the ascorbic acid occurred in severely chilled bananas.

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Color. Jansen (1969) stated that the most important and noticeable change in sliced frozen peaches was browning due to the enzyme, polyphenoloxidase, which catalyzed the reaction of phenolic compounds to quinones which in turn became brown polymers. Polyphenoloxidase color reactions occurred during frozen storage of apple slices, bananas and avocados, according to Jansen (1969).

According to Cain (1967) oxygen permeable packaging materials contribute to browning because oxygen is requisite for this reaction. Guadagni et al. (1957) stated that significant color changes in frozen peach slices appeared in approximately one-third of the time that detectable flavor changes occurred when fruits were stored at -9 to -4^{o}C.

Flavor. According to Jansen (1969), texture, appearance, odor and taste contribute to flavor; hence, any changes from the desirable or normal would constitute off-flavor. Guadagni et al. (1957) stated that the flavor of severely browned peach slices was altered as a result of browning and the flavor change varied directly with the degree of intensity of browning. They reported there was an essentially linear relationship between quality scores assigned by a trained panel and number of brown slices per package.

One type of flavor change in frozen vegetables is termed "delay" off-flavor or a haylike flavor. Kohman et al., as cited by Jansen (1969), found the bruising of some vegetables produced this "delay" off-flavor.

Strawberries have been reported to have "off-flavors" when they were frozen slowly (Heiss, 1942) although, freezing rates generally have more effects on texture of fruits rather than flavor (Heiss, 1942).

Use of Additives

The most serious defect present in fruits which have been frozen is a change in the textural characteristics. Light-colored fruits, such as apples and bananas, are subject to undesirable color changes caused by enzymatic browning during and after thawing (Guadagni, 1969). The use of additives to prevent textural or color changes will be discussed.

Additives to deter textural changes

Calcium salts have been used to prevent softening of canned fruits and vegetables, especially tomatoes. According to Loconti *et al*. (1941), the essential reaction is the formation of calcium pectate in the tissues by the reaction of calcium ions with pectic acid. The formed salts support the tissues of the tomatoes against softening and disintegration during processing.

Siegel (1939) reported that calcium chloride, being a salt of a strong acid and highly dissociated produces a more satisfactory "calcium effect" than other calcium salts of weak acids. Kertesz *et al*. (1938) indicated three methods of applying calcium; 1) dipping the peeled fruit into a calcium chloride solution prior to canning, 2) adding calcium chloride *per se* to the can before sealing, and 3) using combination salt tablets which contain calcium chloride.

According to Powers *et al*. (1961), one of the problems connected with the use of calcium compounds is that some of them such as calcium chloride, when used above certain levels impart a bitter or salty taste to the product.

In addition to firming plant tissue, calcium chloride has been reported to offer a new means for helping to control heat damage during drying and non-enzymatic browning during storage at warm temperatures for products such as dehydrated potatoes (Simon *et al.*, 1955).

Additives to deter color changes

Guadagni (1969) stated that the most commonly used method to minimize color changes during freezing and thawing of fruit is by packing them in sucrose syrup containing ascorbic acid. With this method, the factors involved in preventing color changes are the amount of ascorbic acid and the extent of oxygen exclusion effected by the syrup.

Ascorbic acid. Ascorbic acid, both L- and d-forms, has been introduced for the control of enzymatic and autooxidative discoloration. The L-form is widely used in preventing the discoloration of fruit during freezing storage. It acts primarily by reducing the oxygen present in or surrounding the fruit tissues and in maintaining a reducing condition in the tissues of the fruit (Esselen *et al.*, 1949; DuBois, 1949). According to Jansen (1969), ascorbic acid functions not only by reducing the oxygen surrounding the fruit tissues but also by reversing the browning reaction at the quinone stage.

Von Loesecke (1949) indicated that color changes in frozen fruit could be retarded by use of ascorbic acid in combination with citric acid. The citric acid probably functioned to change the pH, thus rendering enzymes inactive and permitting the ascorbic acid to act as an antioxidant.

Sugar. Sugar and sugar solutions are used in freezing of fruit to exclude direct contact of the fruit tissue with oxygen (Joslyn et al., 1948). Thus, sugar and sugar solutions help preserve color and in addition, act as an enhancer of the natural fruit flavor (Guadagni, 1969).

According to Joslyn et al. (1951), the sugar solutions inhibit discoloration by reducing the concentration of dissolved oxygen, hence, reducing the rate of oxygen diffusion into fruit tissue. Joslyn (1949) also reported that concentrated sugar solutions exert an inhibiting effect on fruit oxidases. Quin (1929) as cited by Joslyn et al. (1951), reported when solutions were present in the same concentration, the retarding effect of sucrose was greater than that of glycerol or dextrose.

Tressler (1943) indicated that in addition to protecting the fruit from air and retarding enzyme actions, sugar solutions acted to reduce evaporation of the more volatile esters and other compounds responsible for the characteristic aroma and flavor of the fruit. He also reported that sucrose solutions penetrated into the fruit during freezing, storage and thawing thus improving the flavor of sour fruit.

EXPERIMENTAL PROCEDURE

This study was designed to determine the effects of freezing on the quality characteristics of bananas. For this purpose, sliced bananas were frozen in sucrose syrup concentrations of 20 and 40% and individually quick frozen (IQF) after dipping in 40% sucrose syrup. All syrups contained an ascorbic acid/citric acid mixture (ACM).

A second purpose of this study was to investigate the effect of a firming agent, calcium chloride ($CaCl_2$), on the textural qualities of bananas. Therefore, 0.2% $CaCl_2$ was added to both the 20 and 40% sugar syrups and the sliced bananas in these syrups were compared with those in syrups containing no $CaCl_2$.

To investigate the effectiveness of the ACM in maintaining quality during freezing and subsequent storage by the IQF method, two levels of ACM were used. One of the levels was the same as that used for sliced bananas frozen in syrup while the second level contained three times as much ACM.

Hence, the six variables included in this study were as follows:

1. 20% syrup + 1.0% ACM
2. 20% syrup + 1.0% ACM + 0.2% $CaCl_2$
3. 40% syrup + 1.0% ACM
4. 40% syrup + 1.0% ACM + 0.2% $CaCl_2$
5. IQF (40% syrup + 1.0% ACM)
6. IQF (40% syrup + 3.0% ACM)

Three replications of each variable were subjected to sensory evaluation and objective and chemical measurements in the fresh unfrozen state, after frozen storage of two to three weeks, and after frozen storage of three months. Each replication consisted of three identical containers of bananas.

Ingredient Procurement

Chiquita brand, Honduras grown bananas were procured through a local wholesaler. All bananas were sorted according to color. They were then held at room temperature (21°C) until the desired ripeness, as indicated by color, was attained and then they were processed.

Granulated sugar and reagent grade $CaCl_2$[1] were each obtained from common lots. Bottles of an ascorbic acid/citric acid mixture (ACM)[2] were thoroughly blended to insure a common lot.

Syrup Formulas

Syrups for the six variables of this study were prepared according to the formulas given in Table 3. The weight of each ingredient was calculated using the following formula based on specific gravities of the 20 and 40% syrups.[3]

Grams = Volume (ml) X Sp Gr of Syrup·Conc X % Ingredient

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[1] Mallinckrodt Chemical Works, St. Louis.

[2] Product of Chas. Pfizer & Co., Inc., New York, 10017. Contains 15% citric acid, 7% ascorbic acid, 7% sucrose, 1% sodium silico aluminate.

[3] <u>Handbook of Chemistry and Physics</u>, 41st ed., 1959-1960, Chemical Rubber Publishing Co., 2310 Superior Ave., N.E., Cleveland.

Table 3. -- Formulas used in preparation of syrups.

Ingredients	Frozen in Syrup Variable				IQF Variable	
	1	2	3	4	5	6
	g					
Sucrose	1784	1784	3882	3882	3882	3882
Water, Distilled	7135	7135	5823	5823	5823	5823
ACM	89.183	89.183	97.053	97.053	97.053	291.159
$CaCl_2$	. . . .	17.837	. . . .	19.411	. . . .	. . . .

A Toledo torsion balance, 5-kg capacity, was used for weighing sugar and water. ACM and $CaCl_2$ were weighed to the nearest 0.000 g using a Mettler balance, Model H-15.

To prepare syrups, appropriate weighed quantities of sucrose and water were heated over medium heat in stainless steel pans with constant stirring until all sucrose was dissolved. Syrups were cooled for approximately 24 hr in a $5^{o}C$ refrigerator before the appropriate amounts of $CaCl_2$ and/or ACM were added. Concentrations of syrups were checked using an Abbé refractometer.

Preparation of Banana Slices

Bananas of the same degree of ripeness were peeled and cut into 3/8-in slices using a household-type, wire butter cutter. Banana slices were put into distilled water in a stainless steel bowl for about 2 min until the quantity needed for each container had been cut. All banana slices were frozen and stored at $-23^{o}C$ until subsequent evaluation.

Banana slices frozen in syrup

One hundred and eighty grams of banana slices were drained on a stainless steel screen for approximately 10 sec before they were put into coded, plastic freezer containers and covered with 250 ml of syrup. Waxed paper was crumpled and placed on top of the bananas to hold the slices beneath the surface of the syrup.

IQF banana slices

Thirty six slices of bananas at room temperature were dipped into 250 ml of the specified, chilled syrup with no stirring for approximately 2 min. Most of the slices sunk in the syrup but approximately 8 to 11% floated at the surface. To allow for air circulation, slices were then arranged in a single layer on a perforated sheet (approximately 4 holes/in^2) of waxed paper which covered a 12" x 12" wire cake cooling rack. After freezing for an hour, the banana slices were placed in polyethylene bags 0.75 mil in thickness and closed with metal twist closures. The closed bags were put into coded, paraffin waxed quart freezer cartons and stored until subsequent evaluation.

Fresh, unfrozen banana slices

Immediately prior to sensory evaluations and objective and chemical measurements, three replications of fresh bananas from the common lot and of the same degree of ripeness were prepared as outlined above with the following exceptions. Rather than freezing and subsequent thawing, these banana slices in syrup were chilled at 5°C prior to evaluation. In addition, objective and chemical measurements were conducted on fresh banana slices without the added syrup.

Defrosting Procedures

Sensory evaluations showed a preference for defrosted banana slices containing a few ice crystals. Hence, defrosting times which permitted a few ice crystals to remain in the slices were established through preliminary investigations.

For sensory evaluations and objective measurements, banana slices frozen in 20% syrups were defrosted for approximately 8 1/2 hr in a 5°C refrigerator, banana slices frozen in 40% syrups were defrosted for approximately 7 hr while IQF banana slices were defrosted in single layer for approximately 2 hr in individual glass dishes covered with Saran wrap. The minimal amount of liquid which drained from the slices during thawing was left in the dishes. For chemical measurements, all variables of banana slices frozen in syrup were defrosted for approximately 15 hr while IQF slices, still in their original freezing bag, were defrosted for approximately 2 hr. The liquid that drained from the IQF slices during thawing was left in the bag.

Sensory Evaluations

A six-member taste panel was utilized to determine the visually-judged texture ("visual texture"), color, mouth feel and flavor of banana slices as well as clarity of syrup of slices frozen in syrup. All attributes were scored on 5-point rating scales and any additional comments from judgments were noted. The rating scales appear in the Appendix along with instructions given to the taste panel members.

For evaluation, all samples were coded with random numbers. Nine test sessions were used with six samples presented at each session. Banana slices were served in glass dishes placed on white trays. Conditions of lighting and environment were constant for each session.

Objective Measurements

Objective tests were used to evaluate color and texture of banana slices prior to freezing, after freezing and after frozen storage of three months. Fresh banana slices with no added syrup were tested for comparison.

Color measurements

Color of banana slices was measured using a Hunter color-difference meter, model D-25. The instrument was standardized with a yellow tile (L, 82.8; a_L, -3.5; b_L, 26.2) covered with an optical lens in preparation for determination of L (lightness), a_L (greenness or redness) and b_L (blueness or yellowness) values of the banana slices. Positive values for a_L measurements indicated redness while positive values for b_L measurements indicated yellowness according to the instructions for the instrument.

Slices were randomly taken from the container of banana slices and placed in a single layer in a 88 x 14 mm petri dish and covered with an optical lens. The covered dish was then placed on a white tile under the viewing area and the reading was recorded. A second reading was obtained after rotating the covered dish one-quarter of a turn. The two readings were then averaged.

Texture measurements

Texture of banana slices was measured using the standard shear-compression cell of an Allo-Kramer shear press, model SP-12, equipped with an electronic recorder, model E2EZ. The 100-lb proving ring, 100% range, 25 lb of pressure and a 30-sec downstroke were used for this measurement.

Banana slices were poured into a screen and drained for 10 sec before weighing to the nearest gram. A 100-g sample was randomly selected and placed in the lower assembly of the cell in a random manner and values for texture were recorded as the upper assembly sheared through the banana slices. Both sections of the cell assembly were rinsed with tap water between each evaluation. Texture of the bananas was expressed as pounds force per gram using the following formula.

$$\frac{\frac{\text{Maximum graph reading}}{100} \times \frac{\text{Range}}{100} \times \text{Ring}}{\text{Sample weight (g)}}$$

Chemical Measurements

The ascorbic acid content was determined for samples prior to freezing, after freezing, and after frozen storage. Fresh banana slices without added syrup and syrups of the six variables were also analyzed for comparison. For accurate calculations of ascorbic acid content, moisture determinations were also conducted.

Moisture determinations

Following the procedure outlined by A.O.A.C. (1960) the moisture content of the bananas was determined. Defrosted banana slices were drained on a screen for 10 min before two slices were randomly selected for this analysis. The two banana slices were mashed, divided approximately equally, and duplicate samples ranging in weight from 2.3 to 5.0 g were weighed into dried, tared aluminum moisture dishes, using a Mettler balance, model H-15. The samples were dried for 6 hrs at $70^{o}C$ under a vacuum of 28 in. Hg, using a Labline Vacuum Oven Cat. No. 3615. The duplicate determinations were then averaged.

Ascorbic acid determinations

The modified osazone method described by Schwartz et al. (1955) was used to determine total ascorbic acid. After draining on a metal screen for 10 min and standing at room temperature for about 5 min while samples for moisture analyses were weighed, a 25 g sample of banana was blended for 2 min with 350 ml of 0.5% oxalic acid and 10 g filter aid[1] in a Waring blender set at low speed. After filtering through Whatman No. 4 filter paper, a 2 ml aliquot of the filtrate was pipetted into each of three 30 ml test tubes. One drop of 2,6-dichlorophenolindophenol was added to each tube. After shaking each tube, 2 ml of 1% thiourea was added to each tube and then 1 ml of 2% 2,4-dinitrophenyl hydrazine was added to two of each set of three test tubes. All samples including the blank containing no 2,4-dinitrophenyl hydrazine were incubated at $37^{o}C$ for 3 hr. After incubation, 5 ml of $HCl\text{-}H_3PO_4$ (3:2) were added to each sample along with 1 ml of 2% 2,4-dinitrophenyl hydrazine to the blank.

Percentage of transmittance of each sample was determined after shaking each tube, using a Beckman DB-G Grating Spectrophotometer set at a wave length of 540 nm. Duplicate readings were averaged for each variable

[1]Hiflo celite, Johns-Manville products.

and the amount of total ascorbic acid, expressed as mg ascorbic acid/100g sample (wet weight), was calculated using values from a standard curve which plotted percentage transmittance for known solutions of 0.002 mg, 0.004 mg, 0.008 mg, 0.012 mg, 0.016 mg ascorbic acid analyzed using the procedure as outlined. The formula follows.

Mg Ascorbic Acid/100g sample (wet weight) = Curve value x 2 x Total volume

RESULTS AND DISCUSSION

This study was designed to determine the effects of freezing on the quality characteristics of banana slices frozen in 20 and 40% sucrose syrup and individually quick frozen (IQF) after dipping in 40% sucrose syrup. All syrups contained an ascorbic acid/citric acid mixture (ACM). This study also investigated the effect of calcium chloride ($CaCl_2$) on the textural qualities of frozen bananas; therefore, $CaCl_2$ was added to 20 and 40% syrups and the bananas in these syrups were compared with those in syrups containing no $CaCl_2$. The effectiveness of ACM in maintaining quality during freezing and subsequent storage by the IQF method was determined by using two levels of the mixture. Three replications of each variable were subjected to sensory evaluation and objective and chemical measurements in the fresh unfrozen state, after freezing and after frozen storage of three months.

Sensory Evaluation of Banana Slices

A six-member taste panel evaluated the banana slices for visual texture, color, mouth feel and flavor as well as clarity of syrup for approximate samples using a 5-point rating scale. Treatment and variable averages for the panelists of three replications appear in the Appendix, Table 17. Mean squares obtained through analyses of variance are shown in Table 4.

Table 4. --Analyses of variance for determining the effect of treatments and variables on the sensory evaluations of sliced bananas.

Source of Variance	Degrees of Freedom	Mean Squares				Degrees of Freedom	Mean Squares
		Visual Texture	Color	Mouth Feel	Flavor		Clarity of Syrup
Treatment	2	8.345**	13.355**	25.207**	5.805**	2	1.700**
Variable	5	1.726**	3.402**	0.109	0.074	3	1.173**
Interaction	10	0.225	1.206**	0.334	0.142	6	0.255
Subtotal	17	1.621**	3.281**	3.195**	0.788**	11	0.768**
Within	36	0.119	0.233	0.172	0.221	24	0.140
Total	53					35	

**Significant at 1 per cent level of probability.

Visual texture

Averages, standard deviations and statistical analyses for sensory evaluations of visual texture are shown in Table 5. When analyzed for differences between treatments, fresh banana slices had significantly higher ($P<0.01$) averages of 4.3 for visual texture than either frozen or frozen-stored banana slices, both of which had average scores of 3.1. Because there was no significant difference between visual texture scores for frozen and frozen-stored bananas, the data suggest it was the freezing and/or thawing process *per se* which affected textural qualities thus supporting the conclusions of Guadagni (1969).

All variables in 40% syrup (Variables 3, 4, 5, 6) scored significantly higher ($P<0.01$) in visual texture than variables in 20% syrup (Variables 1, 2). Average scores for banana slices in 40% syrup with and without $CaCl_2$ and IQF slices in syrups containing the regular amount and increased ACM were 3.9, 3.5, 3.6 and 4.0, respectively while scores averaged 2.9 and 3.0 for banana slices in 20% syrup with and without $CaCl_2$, respectively. Comments of the panelists indicated that the banana slices in 20% syrup showed sloughing and appeared soft.

The IQF slices dipped in syrup containing increased ACM (Variable 6) were judged significantly higher ($P<0.05$) in visual texture with an average score of 4.0 than IQF slices dipped in syrup containing the regular amount of ACM (Variable 5) with an average score of 3.6, which, according to the panelists, appeared soft and resembled baked fruit. The addition of $CaCl_2$ (Variables 2, 4) did not significantly affect the scores for visual texture.

Table 5. --Averages, standard deviations and statistical analyses for sensory evaluations of visual texture of fresh, frozen and frozen-stored banana slices.

Variables	Treatment			Statistical Significance[a]	
	Fresh A	Frozen B	Frozen-stored C	$P < 0.01$	$P < 0.05$
1. 20%	4.0 ± 0.4	2.3 ± 0.5	2.7 ± 0.2		
2. 20% + $CaCl_2$	3.7 ± 0.6	2.8 ± 0.3	2.3 ± 0.4	B, C < A	
3. 40%	4.5 ± 0.3	3.0 ± 0.2	3.1 ± 0.1		
4. 40% + $CaCl_2$	4.6 ± 0.4	3.5 ± 0.4	3.6 ± 0.4	2, 1 < 3, 5, 4, 6	5 < 6
5. IQF	4.1 ± 0.6	3.2 ± 0.3	3.4 ± 0.2		
6. IQF + 3X ACM	4.8 ± 0.1	3.9 ± 0.1	3.2 ± 0.2		
Treatment Average	4.3 ± 0.4	3.1 ± 0.6	3.1 ± 0.5		

[a]Values underscored by the same line are not significantly different (Duncan, 1957).

Color

The data of this investigation as presented in Table 6 showed that fresh banana slices were scored significantly higher ($P<0.01$) in color than either frozen or frozen-stored slices thus suggesting reactions occurring during the freezing and/or thawing process were responsible for color changes. Fresh banana slices had an average color score of 4.6, thus indicating the banana slices were creamy yellow with very little surface browning. Frozen and frozen-stored banana slices averaged 3.2 and 2.9, respectively, indicating surface browning on the slices which was most evident in the placenta. The high standard deviations indicate considerable variance among the judges in their evaluations of color.

When analyzed for variance between variables, the data showed banana slices in syrup (Variables 1, 2, 3, 4) were significantly lighter ($P<0.01$) in color than IQF slices (Variables 5, 6). Average scores of 3.8, 3.9, 3.9 and 4.1 were recorded for slices in 20% syrup with and without $CaCl_2$ and 40% syrup with and without $CaCl_2$, respectively, while IQF banana slices in syrups with regular and an increased amount of ACM averaged 2.5 and 3.1, respectively, for color scores. Guadagni (1969) stated the use of syrups containing ascorbic acid to pack fruits for freezing was beneficial in preventing color changes. The syrup functioned to exclude oxygen while the ascorbic acid maintained a reducing condition in the tissues of the fruit (Esselen *et al*., 1949, DuBois, 1949).

Apparently, the concentration of the syrup was not an important factor in preventing color changes because no significant differences existed between Variables 1, 2 and Variables 3, 4 which contained 20 and 40%

Table 6. --Averages, standard deviations and statistical analyses for sensory evaluations of color of fresh, frozen and frozen-stored banana slices.

Variable	Treatment			Statistical Significance[a]
	Fresh A	Frozen B	Frozen-stored C	$P < 0.01$
1. 20%	4.7 ± 1.0	3.9 ± 0.7	3.1 ± 0.6	
2. 20% + $CaCl_2$	4.6 ± 0.2	3.3 ± 0.7	3.6 ± 0.6	$\underline{B, C} < A$
3. 40%	4.5 ± 0.1	3.9 ± 0.2	4.0 ± 0.4	
4. 40% + $CaCl_2$	4.2 ± 0.4	3.9 ± 0.3	3.6 ± 1.2	$\underline{5, 6} < \underline{2, 1, 4, 3}$
5. IQF	4.4 ± 0.6	2.0 ± 0.4	1.2 ± 0.3	
6. IQF + 3X ACM	4.9 ± 0.2	2.3 ± 0.2	2.1 ± 0.3	
Treatment Average	4.6 ± 0.2	3.2 ± 0.9	2.9 ± 1.1	

[a]Values underscored by the same line are not significantly different (Duncan, 1957).

syrups, respectively. The increased amount of ACM in the syrup used for dipping IQF banana slices (Variable 6) was not significantly more effective than the regular amount of ACM (Variable 5) in preventing color changes. Also, the use of $CaCl_2$ (Variables 2, 4) had no effect on color changes.

Mouth feel

Fresh banana slices scored significantly higher ($P < 0.01$) in mouth feel than frozen-stored slices which in turn scored significantly higher ($P < 0.01$) than frozen slices. The data are presented in Table 7. The average score of 4.2 indicated fresh banana slices were soft, retained their shape and yielded readily to pressure of the mouth. Frozen slices with an average score of 1.9 were considered by the panelists as moderately soft while frozen-stored slices with an average score of 2.6 were considered slightly less soft. Perhaps these data, indicating an improvement in mouth feel quality during frozen storage, reflect variances in the evaluations of the panelists rather than actual changes in the quality of the banana slices. As indicated by scores of visual texture and color the data suggest the freezing and/or thawing process *per se* damaged the cellular structure of the banana slices.

No significant differences in mouth feel were noted between variables. Rank ordering of the average scores denoted no trends regarding the effectiveness of $CaCl_2$ or syrup concentration in preventing textural changes in banana slices.

Flavor

Averages, standard deviations and statistical analyses of flavor scores are presented in Table 8. Fresh banana slices averaging 3.7, scored significantly higher ($P < 0.01$) in flavor than either frozen or frozen-stored slices, both averaging 2.8, which did not differ significantly. These data indicate the freezing process was detrimental to the

Table 7. --Averages, standard deviations and statistical analyses for sensory evaluations of mouth feel of fresh, frozen and frozen-stored banana slices.

Variable	Treatment			Statistical Significance[a]
	Fresh A	Frozen B	Frozen-stored C	$P < 0.01$
1. 20%	4.1 ± 0.1	2.0 ± 0.3	2.5 ± 0.3	
2. 20% + $CaCl_2$	4.3 ± 0.3	2.0 ± 0.6	2.4 ± 0.3	B < C < A
3. 40%	4.4 ± 0.2	1.4 ± 0.3	2.5 ± 0.4	
4. 40% + $CaCl_2$	4.5 ± 0.5	1.8 ± 0.7	2.9 ± 0.4	
5. IQF	4.1 ± 0.3	1.7 ± 0.6	2.5 ± 0.3	
6. IQF + 3X ACM	3.7 ± 0.8	2.5 ± 0.3	2.6 ± 0.1	
Treatment Average	4.2 ± 0.3	1.9 ± 0.4	2.6 ± 0.2	

[a]Values underscored by the same line are not significantly different (Duncan, 1957).

Table 8. --Averages, standard deviations and statistical analyses for sensory evaluations of flavor of fresh, frozen and frozen-stored banana slices.

Variable	Treatment			Statistical Significance[a]
	Fresh A	Frozen B	Frozen-stored C	$P < 0.01$
1. 20%	3.6 ± 1.1	3.1 ± 0.4	2.7 ± 0.4	
2. 20% + $CaCl_2$	3.7 ± 0.4	2.6 ± 0.1	2.6 ± 0.2	$\underline{B, C} < A$
3. 40%	3.9 ± 0.4	2.9 ± 0.4	2.7 ± 0.2	
4. 40% + $CaCl_2$	4.0 ± 0.5	2.4 ± 0.4	2.8 ± 0.6	
5. IQF	3.6 ± 0.3	2.7 ± 0.6	2.8 ± 0.4	
6. IQF + 3X ACM	3.6 ± 0.8	2.8 ± 0.1	3.0 ± 0.3	
Treatment Average	3.7 ± 0.2	2.8 ± 0.2	2.8 ± 0.1	

[a]Values underscored by the same line are not significantly different (Duncan, 1957).

banana flavor although panelists may have been influenced by the appearance of the slices in their judgments of flavor. According to Jansen (1969) appearance contributes to flavor of fruit.

No significant differences were noted in flavor evaluations between variables. According to Power et al. (1961), $CaCl_2$ imparts a bitter or salty taste to the product when used above a certain level. The panelists indicated they detected a bitter or foreign flavor in the banana slices in syrups containing $CaCl_2$ and the off-flavors were more evident in slices in 20% syrup than in slices in 40% syrup, perhaps because the increased sweetness of the 40% syrup masked off-flavors more than the 20% syrup did. Apparently excessive levels of $CaCl_2$ were used in this study or perhaps the off-flavors resulting from its use were more apparent with bananas than with other fruits.

The data present no definite pattern regarding the effect of syrup concentration on the flavor of banana slices. Panelists indicated banana slices in 40% syrup (Variables 3) and IQF slices in syrup containing an increased amount of ACM (Variable 6) were too sweet. IQF slices in syrup containing the regular amount of ACM (Variable 5) were considered too sweet by the panelists in the fresh state; however, after the freezing process, panelists said a foreign flavor was present. The diverse opinions of the panelists are evident in the large standard deviations as shown in Table 8.

Clarity of syrup

Panelists were asked to evaluate the clarity of syrup for appropriate variables as an indication of the tissue breakdown during the preparing, freezing and/or storing processes. Averages, standard deviations and statistical analyses for clarity of syrup evaluations are presented in Table 9.

Syrups of fresh slices contained significantly fewer ($P < 0.01$) particles than either syrups of frozen or frozen-stored slices, both of which scored the same, again suggesting the freezing and/or thawing process *per se* was responsible for the plant tissue breakdown. Fresh banana slices scored an average of 4.0 indicating the syrup was very slightly cloudy with few banana particles present. Frozen and frozen-stored slices averaged 3.3 showing an increased number of banana particles were present.

Slices in 20% syrup (Variables 1, 2) contained significantly more ($P < 0.01$) particles than slices in 40% syrup containing $CaCl_2$ (Variable 4) and significantly more ($P < 0.05$) particles than slices in 40% syrup with no $CaCl_2$ (Variable 3). Average scores of 3.3, 3.2, 4.0, and 3.7 were recorded for slices in 20% syrup with and without $CaCl_2$ and 40% syrup with and without $CaCl_2$, respectively. These data indicate percentage of sucrose in the syrup was more beneficial in preventing tissue breakdown than was $CaCl_2$.

Table 9. --Averages, standard deviations and statistical analyses for sensory evaluations of clarity of syrup of fresh, frozen and frozen-stored banana slices.

Variable	Treatment			Statistical Significance[a]	
	Fresh A	Frozen B	Frozen-stored C	$P < 0.01$	$P < 0.05$
1. 20%	3.4 ± 0.4	2.9 ± 0.4	3.2 ± 0.4		
2. 20% + $CaCl_2$	3.5 ± 0.5	3.4 ± 0.4	3.0 ± 0.3	$\underline{B, C} < A$	
3. 40%	4.5 ± 0.1	3.3 ± 0.6	3.2 ± 0.3		
4. 40% + $CaCl_2$	4.5 ± 0.5	3.7 ± 0.3	3.7 ± 0.2	1, 2 < 4	$\underline{1, 2} < 3$
Treatment Average	4.0 ± 0.6	3.3 ± 0.3	3.3 ± 0.3		

[a]Values underscored by the same line are not significantly different (Duncan, 1957).

Objective Measurements

Color of banana slices was determined using a Hunter color-difference meter while texture was measured with an Allo-Kramer shear press. Mean squares for the analyses of variance of the data are shown in Table 10 while the data used for these calculations are presented in the Appendix, Table 18.

Color

Analyses of variance for color measurements expressed as L or lightness, a_L or redness and b_L or yellowness values revealed highly significant differences among treatments. Highly significant differences were also noted between variables for b_L values.

The L or lightness values. Averages, standard deviations and statistical analyses for L values are shown in Table 11. Fresh banana slices with syrup were significantly lighter ($P < 0.01$) than either frozen or frozen-stored slices which did not differ significantly. Average values of 63.0, 58.4 and 57.2 were noted for fresh, frozen and frozen-stored slices, respectively. A value of 66.0 was noted for fresh banana slices with no syrup thus showing these slices appeared lighter in color than syrup treated samples. Frozen and frozen-stored banana slices appeared slightly brown indicating enzymatic browning or other color reactions had taken place during the freezing, storing and/or defrosting processes. Jansen (1969) indicated polyphenoloxidase color reactions occurred during frozen storage of bananas. The significant interaction ($P < 0.05$) between

Table 10. --Analyses of variance of Hunter color-difference meter values and Allo-Kramer shear press measurements of fresh, frozen and frozen-stored banana slices.

Source of Variance	Degrees of Freedom	Mean Squares			
		Color Values			Shear-press Values
		L	a_L	b_L	
Treatment	2	164.23**	10.415**	18.700**	1371.175**
Variable	5	1.27	0.774	18.470**	533.008**
Interaction	10	5.65*	0.252	3.861	5.441
Subtotal	17	23.018**	1.601**	9.904**	321.282**
Within	36	2.332	0.408	1.220	38.281
Total	53				

**Significant at the 1 per cent level of probability.

*Significant at the 5 per cent level of probability.

Table 11. --Averages, standard deviations and statistical analyses for L values of fresh, frozen and frozen-stored banana slices.

Variable	Treatment			Statistical Significance[a]
	Fresh A	Frozen B	Frozen-stored C	$P < 0.01$
1. 20%	62.7 ± 1.5	57.8 ± 2.7	56.7 ± 1.2	
2. 20% + $CaCl_2$	63.2 ± 0.3	57.8 ± 0.8	56.8 ± 1.0	
3. 40%	61.6 ± 1.1	58.2 ± 2.2	59.2 ± 1.0	$\underline{C, B} < A$
4. 40% + $CaCl_2$	61.6 ± 2.1	59.3 ± 1.3	58.5 ± 1.8	
5. IQF	64.0 ± 0.9	58.8 ± 1.7	54.9 ± 2.4	
6. IQF + 3X ACM	64.6 ± 1.2	58.3 ± 1.7	57.2 ± 0.2	
Treatment Average	63.0 ± 1.2	58.4 ± 0.6	57.2 ± 1.5	

[a]Values underscored by the same line are not significantly different (Duncan, 1957).

treatments and variables suggested the differences in lightness values were somewhat dependent on the syrup concentration and/or additives used. No significant differences were noted between variables for lightness values, however. The correlation coefficient of 0.67 between L values and sensory evaluations of color showed a highly significant relationship between the two sets of data.

The a_L or redness values. The data as presented in Table 12 showed frozen-stored banana slices were significantly redder ($P < 0.01$) than either fresh or frozen banana slices with syrup which were not significantly different. The a_L values averaged 1.1, 1.5 and 2.6 for fresh, frozen and frozen-stored slices with syrup, respectively, and 1.1 for fresh banana slices with no syrup. Data for the frozen and frozen-stored banana slices probably reflect the redness characteristics of discolored slices. These data suggest that enzymatic browning or other color reactions continued or occurred during frozen storage. Von Loesecke (1949) indicated darkening due to enzymatic action, was apparent even during frozen storage of bananas. No significant differences were found in redness values between variables. However, a highly significant negative correlation coefficient of -0.49 showed an inverse relationship between a_L values and sensory evaluations of color.

Table 12. --Averages, standard deviations and statistical analyses for a_L values of fresh, frozen and frozen-stored banana slices.

Variable	Treatment			Statistical Significance[a]
	Fresh A	Frozen B	Frozen-stored C	$P < 0.01$
1. 20%	0.9 ± 1.0	1.3 ± 1.5	2.6 ± 0.5	
2. 20% + $CaCl_2$	1.1 ± 0.6	0.7 ± 0.5	2.2 ± 0.9	
3. 40%	1.1 ± 0.6	1.8 ± 0.3	2.4 ± 0.6	<u>A, B</u> < C
4. 40% + $CaCl_2$	1.5 ± 0.3	1.2 ± 0.7	2.6 ± 0.4	
5. IQF	0.9 ± 0.4	1.6 ± 0.3	2.7 ± 0.7	
6. IQF + 3X ACM	1.3 ± 0.1	2.2 ± 0.4	3.1 ± 0.1	
Treatment Average	1.1 ± 0.2	1.5 ± 0.5	2.6 ± 0.3	

[a]Values underscored by the same line are not significantly different (Duncan, 1957).

The b_L or yellowness values. The data of yellowness values as presented in Table 13 showed fresh banana slices were significantly more yellow than either frozen or frozen-stored banana slices which were not significantly different. The average values were 23.1, 21.3 and 21.4 for fresh, frozen and frozen-stored banana slices, respectively, and 21.6 for fresh slices with no syrup. These data for frozen and frozen-stored slices support the L and a_L values showing that color reactions and/or enzymatic browning took place during freezing and storing. Color reactions may have also occurred on the surfaces of banana slices with no syrup during the color measurement process. It is also possible that color reactions due to enzymatic browning occurred during defrosting and serving as the banana slices warmed and were exposed to air.

Banana slices frozen in syrup (Variables 1, 2, 3, 4) were significantly more yellow ($P \angle 0.01$) than IQF slices (Variables 5, 6) thereby suggesting the presence of syrup reduced color changes during freezing and subsequent storage and thawing, probably by exclusion of oxygen. In support, Joslyn et al. (1948) indicated sugar syrups excluded direct contact of fruit tissues with oxygen.

Syrup concentration had no effect on color changes since no significant differences attributable to this factor were shown (Variables 1, 2, 3, 4). In addition, the percentage of ACM did not significantly influence the extent of discoloration (Variables 5, 6). Average values of 22.4, 22.2, 23.4, 23.2, 19.9 and 20.7 were determined for slices in 20% syrup with and without $CaCl_2$, slices in 40% syrup with and without $CaCl_2$ and IQF slices in syrup with regular and increased amounts of ACM, respectively.

Table 13. --Averages, standard deviations and statistical analyses for b_L values of fresh, frozen and frozen-stored banana slices.

Variable	Treatment			Statistical Significance[a]
	Fresh A	Frozen B	Frozen-stored C	$P < 0.01$
1. 20%	22.7 ± 1.5	21.1 ± 2.5	22.9 ± 0.5	
2. 20% + $CaCl_2$	23.6 ± 0.7	21.8 ± 0.6	21.9 ± 2.3	B, C < A
3. 40%	23.5 ± 1.3	23.0 ± 0.9	23.1 ± 0.8	
4. 40% + $CaCl_2$	23.5 ± 0.9	23.3 ± 0.7	23.5 ± 0.6	5, 6 < 1, 2, 3, 4
5. IQF	23.0 ± 0.9	19.0 ± 0.6	17.6 ± 0.5	
6. IQF + 3X ACM	22.6 ± 0.4	19.8 ± 0.8	19.6 ± 0.7	
Treatment Average	23.2 ± 0.4	21.3 ± 1.7	21.4 ± 2.3	

[a]Values underscored by the same line are not significantly different (Duncan, 1957).

The correlation coefficient of 0.72 between b_L values and sensory evaluations of color showed a highly significant relationship. Apparently the Hunter color-difference meter and the panelists were measuring the same thing.

Allo-Kramer Shear Press Measurements

Analyses of variance for texture of banana slices as presented in Table 10 showed highly significant differences for both treatments and variables. Averages, standard deviations and further statistical analyses of the data are shown in Table 14.

Fresh banana slices were significantly firmer in texture ($P \angle 0.01$) than either frozen or frozen-stored slices which did not differ significantly. Average lb. force/g values of 0.45, 0.30 and 0.29 were calculated for fresh, frozen and frozen-stored banana slices with syrup and 0.40 for fresh slices without syrup. These data for fresh, frozen and frozen-stored slices correspond to visual texture and mouth feel as evaluated by a sensory panel, the correlation coefficients being 0.63 with visual texture and 0.56 with mouth feel, and indicate it was the freezing and/or thawing process *per se* which affected the textural qualities of the banana slices. Differences between fresh slices with syrup and fresh banana slices without syrup probably reflect sampling differences.

The data showed that IQF slices with the regular amount of ACM in the syrup (Variable 5) were significantly firmer in texture ($P \angle 0.01$) than slices in syrup (Variables 1, 2, 3, 4) while IQF slices with an increased amount of ACM in the syrup differed significantly ($P \angle 0.01$) from only three of the variables in syrup (Variables 1, 2, 3). These

Table 14. --Averages, standard deviations and statistical analyses for shear press measurements of fresh, frozen and frozen-stored banana slices.

Variable	Treatment			Statistical Significance[a]
	Fresh A	Frozen B	Frozen-stored C	$P < 0.01$
	lb force/g			
1. 20%	0.37 ± 0.03	0.27 ± 0.02	0.21 ± 0.01	
2. 20% + $CaCl_2$	0.41 ± 0.01	0.25 ± 0.01	0.25 ± 0.01	$\underline{C, B} < A$
3. 40%	0.42 ± 0.05	0.25 ± 0.02	0.21 ± 0.01	$\underline{1, 3, 2, 4} < 5$
4. 40% + $CaCl_2$	0.49 ± 0.14	0.27 ± 0.04	0.26 ± 0.01	$\underline{1, 3, 2} < 6$
5. IQF	0.52 ± 0.17	0.43 ± 0.08	0.45 ± 0.07	
6. IQF + 3X ACM	0.47 ± 0.07	0.32 ± 0.03	0.37 ± 0.02	
Treatment Average	0.45 ± 0.10	0.30 ± 0.07	0.29 ± 0.10	

[a]Values underscored by the same line are not significantly different (Duncan, 1957).

data do not show the same rank orderings for the variables as was evident in sensory evaluations of visual texture and mouth feel. Variable averages of 0.30, 0.28, 0.34, 0.29, 0.47 and 0.39 were recorded for slices in 20% syrup with and without $CaCl_2$, slices in 40% syrup with and without $CaCl_2$ and IQF slices with regular and increased amounts of ACM, respectively.

Because there were no significant differences between banana slices in syrups with added $CaCl_2$ (Variables 2, 4) and those in syrups with no added $CaCl_2$ (Variables 1, 3) the data showed that $CaCl_2$ had no firming effects on the banana slices. These data are in disagreement with that of Loconti _et al_. (1941); however, the tomatoes used in their study were heat processed and hence, different results might be expected.

Moisture Content

Values for the moisture content of fresh, frozen and frozen-stored banana slices appear in the Appendix, Table 20. Treatment averages for the moisture content of fresh, frozen and frozen-stored banana slices contained significantly more ($P < 0.01$) moisture than either frozen or frozen-stored banana slices which did not differ significantly . Banana slices frozen in 40% syrup (Variable 3, 4) contained significantly less ($P < 0.01$) moisture than slices frozen in 20% syrup (Variable 1, 2) or IQF banana slices (Variable 5, 6) as shown in Table 15.

Table 15. --Averages, standard deviations and statistical analyses for moisture content of fresh, frozen and frozen-stored banana slices.

Variable	Treatment			Statistical Significance[a]
	Fresh A	Frozen B	Frozen-stored C	$P < 0.01$
	o/o			
1. 20%	75.10 ± 1.51	72.20 ± 1.23	72.67 ± 0.67	
2. 20% + $CaCl_2$	73.97 ± 1.40	72.70 ± 1.20	72.10 ± 1.40	
3. 40%	72.10 ± 1.76	67.40 ± 3.26	66.23 ± 0.51	$\underline{C, B} < A$
4. 40% + $CaCl_2$	71.43 ± 2.41	67.40 ± 1.19	66.93 ± 1.01	$\underline{3, 4} < \underline{5, 6, 2, 1}$
5. IQF	72.60 ± 2.77	70.90 ± 0.53	71.27 ± 1.22	
6. IQF + 3X ACM	72.63 ± 3.72	71.40 ± 0.93	70.90 ± 1.15	
Treatment Average	72.97 ± 1.34	70.33 ± 2.36	70.02 ± 2.74	

[a]Values underscored by the same line are not significantly different (Duncan, 1957).

Ascorbic Acid

Ascorbic acid retention in the banana slices was measured at each period for every variable as an indication of product quality using the modified osazone method (Schwartz et al., 1955) to determine the total ascorbic acid content. Treatment and variable values for each replication appear in the Appendix, Table 19 while mean squares calculated from the data are shown in Table 15. The analyses indicated both treatments and variables contributed to highly significant differences.

Data as shown in Table 16 indicate frozen-stored and frozen banana slices were significantly higher ($P < 0.01$) in total ascorbic acid content than fresh banana slices. This fact is in conflict with the generally accepted procedure of using the disappearance of ascorbic acid as an indication of deterioration in foods. Payne et al. (1967) studied the ascorbic acid retention in corn quick frozen on the cob and reported that the ascorbic acid content was significantly increased immediately after freezing. Furthermore, the ascorbic acid content increased after frozen storage. Schreiber et al. (1958) reported that the increase in the ascorbic acid content of potatoes coincided with a decrease in reducing sugars. Loewus et al. (1958) and Isherwood et al. (1954) stated that ascorbic acid was an intermediate product in carbohydrate metabolism and hence, the generation of the vitamin in frozen-stored products was possible. The results of this study may support these conclusions; but, banana slices may have absorbed ascorbic acid from the syrups during freezing, storing and/or thawing thereby increasing the total content. Also, the moisture content of the frozen and frozen-stored banana slices was

Table 16. --Analysis of variance for determining the effect of treatments and variables on the ascorbic acid content of banana slices.

Source of Variance	Degrees of Freedom	Mean Squares
Treatment	2	65.815**
Variable	5	17.518**
Interaction	10	7.774
Subtotal	17	17.468**
Within	36	2.438**
Total	53	

**Significant at 1 per cent level of probability.

less than the fresh slices, thus contributing slightly to the apparent increase in ascorbic acid in the frozen and frozen-stored slices. Fresh banana slices had an average ascorbic acid content of 12.3 mg/100 g of fruit while frozen and frozen-stored slices contained an average of 15.4 and 15.7 mg/100 g of fruit, respectively.

IQF slices with the regular amount of ACM in the syrup (Variable 5) had significantly lower ($P < 0.01$) ascorbic acid content than banana slices in syrup or IQF slices with an increased amount of ACM in the syrup (Variables 1, 2, 3, 4, 6). In addition, bananas with 40% syrup containing $CaCl_2$ (Variable 4) had less ($P < 0.05$) ascorbic acid than IQF slices in syrup with an increased amount of ACM. Variable averages were 15.2, 14.6, 14.2, 14.6, 12.0 and 16.2 mg/100 g of fruit for slices in 20% syrup with and without $CaCl_2$, slices in 40% syrup with and without $CaCl_2$ and IQF slices with regular and an increased amount of ACM, respectively.

The data indicate the ascorbic acid present on IQF slices in syrup with regular amounts of ACM was utilized to prevent color reactions during freezing, storing and/or thawing; hence, reduced levels were present in this variable.

Fresh banana slices without syrup were analyzed for total ascorbic acid. The data showed an ascorbic acid content of 6.7 mg per 100 g of banana slices. This value was in the range of those reported by Harris et al. (1939) as shown in Table 2.

The syrups used to pack banana slices were also subjected to analysis for total ascorbic acid content using the same methods and storage periods where applicable as for banana slices. Average ascorbic acid contents based on one trial of each of the five syrups containing 1% ACM were

Table 17. --Averages, standard deviation and statistical analysis for ascorbic acid content of fresh, frozen and frozen-stored banana slices.

Variable	Treatment			Statistical Significance[a]	
	Fresh A	Frozen B	Frozen-stored C	$P < 0.01$	$P < 0.05$
	mg/100g				
1. 20%	12.3 ± 2.0	16.3 ± 1.3	15.3 ± 0.4		
2. 20% + $CaCl_2$	12.7 ± 0.8	16.3 ± 1.2	16.5 ± 0.2	$A < \underline{B, C}$	
3. 40%	10.5 ± 1.7	16.0 ± 2.1	17.3 ± 2.0		
4. 40% + $CaCl_2$	10.5 ± 1.8	15.7 ± 3.1	16.3 ± 0.6	$5 < \underline{4, 3, 1, 2, 6}$	
5. IQF	10.6 ± 2.0	13.3 ± 1.3	12.2 ± 0.8		$4 < 6$
6. IQF + 3X ACM	17.0 ± 2.0	15.0 ± 1.0	16.6 ± 0.7		
Treatment Average	12.3 ± 2.5	15.4 ± 1.2	15.7 ± 1.8		

[a]Values underscored by the same line are not significantly different (Duncan, 1957).

27.2 $\pm$ 3.9, 28.7 $\pm$ 2.7 and 27.8 $\pm$ 5.0 for syrups used for fresh, frozen and frozen-stored banana slices, respectively. The standard deviations show considerable variance among the syrups used for each treatment of banana slices. When 3% ACM was added to the syrup, values of 28.3, 34.3 and 35.0 were determined for syrups used for fresh, frozen and frozen-stored banana slices.

SUMMARY AND CONCLUSIONS

The primary purpose of this investigation was to determine the effect of freezing methods in combination with syrup concentration on the quality characteristics of banana slices. A second purpose was to investigate the effect of $CaCl_2$ on the textural qualities of frozen banana slices and the effect of ACM in maintaining color of IQF banana slices. All of the bananas used in this investigation were Chiquita brand obtained from a local wholesaler. All data reported were the average of three replications.

Quality characteristics of the banana slices were evaluated by a six-member taste panel. The results indicated that the visual texture of fresh banana slices was scored significantly higher ($P \angle 0.01$) than either frozen or frozen-stored slices and the banana slices in 40% syrup scored higher ($P \angle 0.01$) than slices in 20% syrup. The addition of $CaCl_2$ did not significantly affect the score of visual texture.

The color of fresh banana slices in syrup was scored significantly higher ($P \angle 0.01$) than either frozen or frozen-stored slices and the slices in syrups were significantly lighter ($P \angle 0.01$) than IQF slices. The addition of an increased amount of ACM in syrups used for IQF slices did not affect the score of color.

Fresh banana slices in syrup scored significantly higher ($P \angle 0.01$) in mouth feel than frozen-stored slices which in turn scored higher

($P < 0.01$) than frozen slices. No significant differences were noted between variables. The improved mouth feel during frozen storage probably reflected the variance in the evaluation by the panelists.

The flavor of fresh banana slices was scored significantly higher ($P < 0.01$) than either frozen or frozen-stored slices, both of which were not significantly different. In addition, no significant differences were noted between variables.

The data for clarity of syrup showed syrups of fresh slices contained significantly fewer ($P < 0.01$) particles than either frozen or frozen-stored slices, both of which scored the same. Slices in 20% syrup contained significantly more ($P < 0.01$) particles than slices in 40% syrup with $CaCl_2$ and significantly more ($P < 0.05$) particles than slices in 40% syrup with no $CaCl_2$. These data, as with scores of visual texture, suggested that percentage of sucrose in the syrup was more effective in preventing tissue breakdown than was $CaCl_2$.

Thus, the fresh banana slices in syrup scored significantly higher ($P < 0.01$) in all of the quality characteristics evaluated by the taste panel than either frozen or frozen-stored banana slices. These data suggested that the freezing and/or thawing process *per se* damaged the cellular structure of the banana slices and was detrimental to the quality characteristics of the banana slices.

The Hunter color-difference meter was used to determine the color of the banana slices. Analyses of the data indicated that fresh banana slices in syrup were significantly lighter and more yellow ($P < 0.01$) in color than either frozen or frozen-stored banana slices, both of which were not significantly different. The frozen-stored banana slices had significantly higher ($P < 0.01$) redness values than either fresh or frozen banana slices. As with the sensory scores for color, slices in syrups were significantly more yellow ($P < 0.01$) than IQF slices. There were no significant differences in lightness and redness values between variables. The addition of an increased amount of ACM in syrups used for IQF slices did not significantly improve the color measurements of IQF slices. Significantly high positive correlation coefficients were found between lightness and yellowness values and sensory scores for color. The high negative correlation coefficient between redness values and sensory scores for color showed an inverse relationship between these two measurements.

The Allo-Kramer shear press was used to determine the texture of the banana slices. Analyses of the data revealed that fresh banana slices were significantly firmer in texture ($P < 0.01$) than either frozen or frozen-stored slices which did not differ significantly. The IQF slices were significantly firmer in texture ($P < 0.01$) than slices packed in syrups. The high correlation coefficients between shear press measurements and visual texture and mouth feel indicated that the instrument and the taste panel evaluated the same quality characteristic of the banana slices.

Ascorbic acid retention in the banana slices was measured by the modified osazone method to determine the total ascorbic acid content. The data indicated that frozen and frozen-stored banana slices were significantly higher ($P < 0.01$) in ascorbic acid than fresh banana slices in syrup, probably due to the generation of the vitamin during frozen storage and/or absorption of ascorbic acid from the syrup. Loss of moisture from frozen and frozen-stored banana slices contributed slightly to an apparent increase in ascorbic acid calculated on a wet weight basis. The IQF slices with the regular amount of ACM in the syrup contained less ($P < 0.01$) ascorbic acid than the other variables, indicating that the ascorbic acid in this variable was utilized to prevent color reactions during freezing, storing and/or thawing.

Thus, fresh banana slices were superior in all subjectively evaluated or objectively measured quality characteristics. The data indicate it was the freezing and/or thawing process *per se* which was detrimental to the quality characteristics of banana slices because few significant differences were found between the characteristics of frozen and frozen-stored banana slices. The data present no clear-cut pattern regarding the effectiveness of syrup concentration in maintaining quality during freezing and storing; however, trends of the data suggest 40% sucrose syrup is superior to 20% sucrose syrup in preserving texture in banana slices. The limited data of this study indicate the use of $CaCl_2$ was not beneficial in preserving quality characteristics and because of the bitter flavor imparted to the banana slices, its use would not be recommended. For IQF banana slices, the use of ACM at a 3% level was more beneficial than use at a 1% level in maintaining quality. No definite pattern existed in the data regarding the merits of syrup-packed or IQF banana slices. The use of ACM increased the ascorbic acid content of banana slices and further increases in the ascorbic acid content were noted after freezing and after storage, probably due to the absorption by the banana slices.

The findings of this study suggest other methods, such as freeze drying, should be investigated for processing bananas. Also, other treatments, such as sulfur dioxide, to deter or prevent color reactions during processing and storing should be investigated. Microscopic study of banana tissues and changes incurred during freezing is basic to further investigations of this processing method. Studies of the enzymes present in bananas as well as changes occurring during processing would provide basic information pertinent to further investigations.

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APPENDIX

Figure 1. INSTRUCTIONS TO TASTE PANEL MEMBERS FOR EVALUATING FROZEN SLICED BANANAS

General Instructions

1. Do not smoke, chew gum, or partake of food or beverage during the 30 minutes before the taste panel session.

2. Sit at the same place in the room for each session.

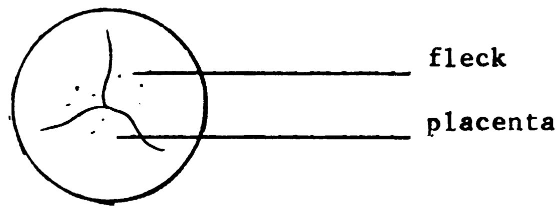
3. Code numbers for each sample will be attached to each dish. Check to be sure the code on the score sheet matches that on the dish. Your name should be written on each score card.

4. Since facial or vocal expressions may influence the scoring of other taste panel members, please avoid these during each session.

5. Samples of sliced bananas will be served to you to evaluate one at a time.

Evaluating Bananas

1. To understand the terminology used in the score card, please study the following drawing.



2. As you evaluate each characteristic, check the space which best fits your judgment for that characteristic.

3. Evaluate the visual texture characteristic first without disturbing the sample and then evaluate the rest of the characteristics.

4. Check to be sure you have evaluated each characteristic for each dish of bananas.

5. You may leave the room after evaluating <u>six</u> samples of bananas.

FROZEN BANANA SLICES

Date ______

Code ______ Judge ______

Score	5	4	3	2	1
TEXTURE Visual	Clean-cut slices.	Slight amount of sloughing.	Moderate amount of sloughing.	Excessive amount of sloughing but with distinguishable slices.	Completely disintegrated. Slices indistinguishable.
COLOR	Creamy yellow with yellow translucent placenta with brown flecks. No surface browning.	Slight surface browning which is more evident in placenta.	Surface browning, more evident in placenta.	Moderate amount of surface browning.	Extremely discolored or darkened.
Mouth Feel	Retains shape when handled carefully but yields readily to pressure of mouth. Placenta softer than carpla. Uniform throughout depth of slice.	Slightly tough or rubbery cellular structure with slightly softened intracellular material.	Tough or rubbery cellular structure with softened intra-cellular material.	Moderately tough or rubbery cellular structure with very soft intercellular material.	Too tough or rubbery cellular structure with extremely soft intra-cellular material.
		Slightly softened throughout banana slice.	Soft throughout banana slice.	Moderately soft throughout banana slice.	Too soft.
FLAVOR	Mellow and pleasantly sweet with very slightly astringent or tart aftertaste.	Perceptible banana flavor.	Slightly perceptible banana flavor.	Very slightly perceptible banana flavor.	No banana flavor.
		Slightly pronounced flavor.	Moderately pronounced flavor.	Very pronounced flavor.	Extremely pronounced or foreign flavor.
CLARITY OF SYRUP	Very few particles of banana present in syrup.	Very slightly cloudy with few particles of banana.	Slightly cloudy with moderate number of particles.	Cloudy with many banana particles.	Very cloudy with disintegrated banana.

COMMENTS:

Figure 2. --Score sheet used for banana slices frozen in syrup.

FROZEN BANANA SLICES

Code ____________ Judge ____________ Date ____________

Score	5	4	3	2	1
TEXTURE Visual	Clean-cut slices.	Very slight amount of softening or wilting.	Slight amount of softening or wilting.	Moderate amount of softening but with distinguishable slices.	Completely disintegrated. Slices indistinguishable.
COLOR	Creamy yellow with yellow translucent placenta with brown flecks. No surface browning.	Slight surface browning which is more evident in placenta.	Surface browning more evident in placenta.	Moderate amount of surface browning.	Extremely discolored or darkened.
Mouth Feel	Retains shape when handled carefully but yields readily to pressure of mouth. Placenta softer than carpla. Uniform (broken) throughout depth of slice.	Slightly rubbery or tough throughout.	Rubbery or tough throughout.	Moderately rubbery or tough throughout.	Too rubbery or tough. Unacceptable.
		Slight surface softening.	Soft on surface with slightly tough core.	Moderately soft with very small tough core.	Too soft throughout. Unacceptable.
FLAVOR	Mellow and pleasantly sweet with very slightly astringent or tart aftertaste.	Perceptible flavor.	Slightly perceptible flavor.	Very slightly perceptible flavor.	No flavor.
		Slightly pronounced flavor.	Moderately pronounced flavor.	Very pronounced flavor.	Extremely pronounced or foreign flavor.

COMMENT:

Figure 3. --Score sheet used for IQF banana slices.

Table 18. --Averages for five panelists of three replications of sensory evaluations of the quality characteristics of fresh, frozen and frozen-stored banana slices.

Quality Character-istic	Variable	Treatment								
		Fresh			Frozen			Frozen-stored		
		1	2	3	1	2	3	1	2	3
Visual Texture	1	3.6	4.3	4.0	2.3	1.8	2.8	2.8	2.8	2.5
	2	3.0	4.0	4.2	2.5	2.8	3.0	2.0	2.2	2.7
	3	4.4	4.8	4.2	3.2	3.0	2.8	3.2	3.0	3.0
	4	4.4	5.0	4.3	4.0	3.4	3.2	4.0	3.2	3.7
	5	3.4	4.5	4.3	3.5	3.0	3.0	3.7	3.3	3.3
	6	4.8	4.8	4.7	4.0	4.0	3.8	3.3	3.2	3.0
Color	1	4.6	4.8	4.7	4.0	3.2	4.5	3.8	2.7	2.8
	2	4.4	4.5	4.8	2.7	4.0	3.3	4.2	3.7	3.0
	3	4.6	4.5	4.5	3.7	4.0	4.0	4.3	4.2	3.5
	4	4.4	4.5	3.8	4.2	4.0	3.6	3.8	2.3	4.7
	5	3.8	4.8	4.7	2.3	1.6	2.0	1.5	1.2	1.0
	6	5.0	5.0	4.7	2.3	2.2	2.5	1.8	2.3	2.3
Mouth Feel	1	4.2	4.0	4.0	1.7	2.0	2.3	2.2	2.5	2.7
	2	4.4	4.0	4.5	1.3	2.3	2.3	2.7	2.2	2.2
	3	4.2	4.5	4.5	1.5	1.6	1.0	2.8	2.7	2.0
	4	4.4	5.0	4.0	2.5	1.6	1.2	3.2	2.5	3.0
	5	3.8	4.3	4.3	2.2	1.8	1.0	2.8	2.2	2.5
	6	4.2	2.8	4.2	2.2	2.7	2.7	2.7	2.5	2.5
Flavor	1	4.0	4.5	2.4	2.7	3.3	3.3	2.7	3.0	2.3
	2	4.0	3.3	3.5	2.7	2.5	2.5	2.7	2.3	2.7
	3	4.0	3.5	4.3	3.2	2.4	3.0	2.7	2.8	2.5
	4	4.4	4.0	3.5	2.3	2.0	2.8	3.3	2.2	3.0
	5	3.8	3.8	3.3	2.2	2.6	3.4	2.8	2.5	3.2
	6	4.4	2.8	3.7	2.8	2.7	2.8	2.8	3.0	3.3
Clarity of Syrup	1	3.0	3.8	3.3	2.8	2.5	3.3	3.0	3.0	3.7
	2	3.0	4.0	3.5	3.0	3.7	3.5	3.2	3.0	2.7
	3	4.4	4.5	4.5	2.8	4.0	3.2	3.5	3.2	3.0
	4	4.2	5.0	4.2	4.0	3.6	3.5	3.7	3.5	3.8

Table 19. --Values for three replications of Hunter color-difference and Allo-Kramer shear press measurements of color and texture, respectively, of fresh, frozen and frozen-stored banana slices.

Measurement	Variable	Treatment								
		Fresh			Frozen			Frozen-stored		
		1	2	3	1	2	3	1	2	3
L Values	1	64.3	61.4	62.3	60.9	56.3	56.3	55.5	56.7	57.9
	2	63.4	62.9	63.2	56.9	58.3	58.1	55.7	57.5	57.2
	3	62.6	60.4	61.7	56.2	60.6	57.7	60.1	58.1	59.4
	4	60.0	60.8	63.9	57.9	60.3	59.7	60.2	56.6	58.8
	5	63.1	64.9	64.1	58.8	60.5	57.2	56.5	52.2	56.1
	6	65.5	65.0	63.3	56.4	59.3	59.3	57.4	57.0	57.1
a_L Values	1	-0.2	1.5	1.5	-0.5	2.0	2.3	2.8	2.0	2.9
	2	0.4	1.6	1.2	0.4	0.4	1.3	1.3	2.2	3.0
	3	0.4	1.4	1.5	2.2	1.7	1.6	2.0	2.1	3.1
	4	1.7	1.6	1.1	1.2	1.9	0.6	3.0	2.5	2.2
	5	1.1	0.4	1.1	1.9	1.5	1.4	3.4	2.0	2.7
	6	1.4	1.4	1.2	2.0	2.6	2.0	3.0	3.1	3.2
b_L Values	1	20.1	23.1	23.9	18.8	20.9	23.7	23.4	22.5	22.7
	2	22.9	23.7	24.3	21.5	22.5	21.4	19.2	23.1	23.4
	3	22.5	24.9	23.1	22.8	22.3	24.0	22.3	23.2	23.8
	4	22.6	24.3	23.6	23.0	22.8	24.1	23.9	23.7	22.8
	5	24.0	22.3	22.6	19.2	18.3	19.4	18.1	17.1	17.5
	6	22.5	22.2	23.0	18.9	20.3	20.1	19.9	20.1	18.8
Shear Press (lb force/g)	1	0.40	0.37	0.34	0.27	0.29	0.26	0.21	0.21	0.20
	2	0.39	0.40	0.42	0.24	0.26	0.26	0.26	0.25	0.23
	3	0.48	0.38	0.41	0.27	0.24	0.24	0.21	0.22	0.21
	4	0.39	0.65	0.45	0.25	0.26	0.31	0.25	0.27	0.26
	5	0.46	0.71	0.40	0.43	0.51	0.36	0.45	0.39	0.53
	6	0.44	0.54	0.42	0.31	0.35	0.31	0.36	0.36	0.40

Table 20. --Values for ascorbic acid content and moisture content of fresh, frozen and frozen-stored banana slices.

	Variable	Treatment								
		Fresh			Frozen			Frozen-stored		
		1	2	3	1	2	3	1	2	3
Ascorbic Acid (mg/100g)	1	10.6	11.7	14.5	17.8	15.3	15.7	15.0	15.8	15.1
	2	11.8	13.1	13.1	15.8	17.7	15.5	16.8	16.4	16.4
	3	11.4	11.5	8.6	13.6	17.1	17.2	16.3	19.6	15.9
	4	8.7	12.3	10.6	12.1	17.3	17.6	15.9	17.0	15.9
	5	8.6	12.5	10.6	12.1	13.0	14.7	12.7	11.3	12.7
	6	15.9	19.3	15.9	13.9	15.8	15.4	16.0	17.4	16.5
Moisture (%)	1	74.87	73.65	76.70	73.10	70.78	72.69	73.04	71.85	73.06
	2	74.12	72.50	75.30	73.90	71.48	72.77	70.45	72.68	73.12
	3	73.39	70.12	72.73	67.60	70.45	64.04	66.75	65.79	66.14
	4	74.10	69.39	70.80	68.05	68.00	65.96	66.27	66.39	68.09
	5	74.14	69.41	74.25	70.25	71.09	71.25	70.15	72.60	71.01
	6	75.38	68.40	74.05	70.40	71.70	72.17	69.99	70.48	72.24