EFFECT OF PREFREEZING TREATMENTS ON QUALITY OF MANGO (*Manguifera Indica L.*) DURING FROZEN STORAGE

by

ANGELA RINCON

(Under the direction of William L. Kerr)

ABSTRACT

At the moment there is a high demand for high-quality fruit ingredients to be used in many food formulations such as pastry and confectionery products, ice cream, frozen desserts and sweets, fruit salads, cheese and yoghurt. The overall objective was to improve quality of frozen mango using two types of food cryoprotection: one was the reduction of water content of the fruit (osmotic dehydration) and the other was the formulation of mango pulp with carbohydrates of different molecular weight to increase frozen stability. Osmotic dehydration was able to modify quality parameters of slices before and after frozen storage. Values for some parameters such as vitamin C, lightness (L^*), chroma (C^*), and firmness for non osmotically dehydrated slices were significantly higher than osmotically dehydrated slices. However, treatments carried out with osmotic solutions (especially those with high concentrations of sucrose) improved significantly the quality of mango slices after frozen storage. Higher moisture losses and solid gain values were reported for slices from the highest osmotic solution concentration. Thus, slices dipped in 30^{o}Brix were better protected against freezing damage. Effects of sucrose concentration on the slices and ripening stage on frozen-thawed mango flavor perception were determined. Six flavor descriptors (color, flavor, sweetness, sourness, firmness and juiciness) were evaluated by a sensory trained panel. All descriptors

were affected by sugar content and ripening stage. To study the effect of mango fruit composition on frozen stability, five pulp samples were prepared and evaluated in terms of glass transition temperature modification and its influence on ascorbic acid retention. State diagrams and sorption isotherms were determined in order to predict freezing storage conditions for the pulps. Glass transition temperature was found to be a function on the composition of the mixture of carbohydrates present on the pulps. As the molecular weight of carbohydrates used for the pulps formulation increased, so did T'_g. Maltodextrin M150, which had the highest T'_g value, had the highest protective effect on ascorbic acid degradation. However, knowledge of T'_g alone was not sufficient to know whether a cryoprotectant is a good cryostabilizer or not. Sensory and textural analysis were recommended in addition to evaluate cryoprotectan effects during frozen storage.

INDEX WORDS: Osmotic dehydration, Mango, Quality, Frozen Storage, Thawing, Texture, Sensory Evaluation, Ripeness, Glass Transition Temperature, State Diagram, Sorption Isotherm, Water Activity, Sugar Composition.

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DEDICATION

I dedicate this thesis to my father, who will live in my heart forever, to my mother and to my sister for their encouragement, love and support.

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CHAPTER 1

INTRODUCTION

Consumer demand has increased for processed products that keep more of their original characteristics. In industrial terms, this requires the development of operations that minimize the adverse effects of processing [1]. Freezing of fruits can result in reduced quality, due to inferior texture and enzymatic action [2]. The consequence is, that during frozen storage, a gradual cumulative and irreversible loss of quality occurs in time [3]. Freezing damage is a consequence of many separate processes such as solute concentration damage, dehydration damage, and mechanical damage from ice crystals[4]. However, there are two possibilities for achieving good protection against freezing damage [5]. One is the reduction in the water content of the product before freezing in order to decrease the amount of crystals formed during this process and thus, minor damage of the cellular membranes occurs and a better conservation of the fruit is assumed [6]. The concentration step is generally realized by air drying [7], osmotic dehydration [8], or a combination of both [9]. Another is the formulation of food with appropriate ingredients to elevate the glass transition temperature (T'_g) of the food which is relative to the freezing temperature (T_f), enhancing the product stability [10].

The dehydration pre-freeze treatments are a useful tool to reduce or avoid the detrimental phenomena of loss of cellular structure and exudates loss at thawing, caused by the physical and chemical actions of freezing of food tissues [11]. While some treatments such as freezing have primarily a stabilizing effect, other steps such as partial dehydration allows structural, nutritional, sensory and other functional properties of the raw material to be modified [12]. Osmotic dehydration, better defined as dewatering impregnation soaking in concentrated solutions (DIS)

[13], can also allow cryoprotection of the cell during freeze-thawing process. The stability of frozen fruits during process and storage could be dependent upon the ability to store the food at a temperature less than its glass transition temperature or the ability to modify the food formulation to increase glass transition temperatures above storage temperature [14].

Cryostabilization provides a means of protecting products, storing for long periods at typical freezing temperatures (-18^{o}C) from changes in texture, structure and chemical composition [5]. Storage of frozen fruits at temperatures below the glass transition temperature (T'_g) can improve the stability of the thawed product greatly, but this would require very low temperatures in the freezer (e.g. -50^{o}C). T'_g is a function of the molecular weight of water compatible monomers, oligomers and high polymers [10]. The selection of the ingredients in a fabricated product allows the food manufacturer to manipulate T'_g and thus, deliberately formulate the raising of T'_g relative to T_f, enhancing the food stability [15].

Mango is the most heavily produced tropical fruit in the world comprising 40% of the tropical fruit production in 1999 [16]. This climacteric fruit has three defined periods [17], and it is highly perishable, due to, among other causes, the activity of degradative enzymes (such as polygalacturonase and cellulase), that are activated in the maturation period, causing reduction of dietary fiber content [18], and softening of the fruit [19]. Mangoes have poor storage qualities and few technologies for longer term storage. Storage methods for mango have been characterized by variable results and the occurrence of physiological disorders [20]. In spite of this, mangos are more and more appreciated by consumers, not only as fresh fruit but also as an ingredient in processed products such as dairy, ice creams, fruit salads or snacks. Mango processing that maintains the product freshness lengthening its shelf life in the market, would be very convenient to increase commercialization in the non-producing countries [21].

One possible method for frozen mango processing could be osmotic dehydration with sugars solutions, working at mild temperatures to preserve the product flavor and other sensory properties [3]. Osmotic dehydration of foods has gained rising interest due to the low temperature (minimal heat damage) and energy requirements. Influence of osmotic dehydration in mangoes has been studied [20]. Much of that work has been focused on the kinetics of solute/water exchange in and out of tissue foods, and in the influence of solutes. However, a deep study from changes in physicochemical, textural and sensory perception during frozen storage has not been reported. Another possible method for frozen mango processing could be to formulate a mango pulp with different molecular weight carbohydrates that raises T'_g and thus, provides a means of protection from changes in chemical composition. Most of the research in this topic has been made in measuring the effect of drying and addition of sucrose to the tissues in collapse or shrinkage of different fruits. Nevertheless, a work that measures the addition of ingredients to mango pulp to manipulate T'_g and thus, obtain freezing stability has not been reported.

The overall objective of the following experiments was to improve quality of frozen mango using two types of food cryoprotection: one was the reduction of water content of the fruit and the other was the formulation of mango pulp with carbohydrates of different molecular weight to increase frozen stability. The objective of the first part of this research was to minimize the adverse effects of freezing in mango fruit using osmotic dehydration as a pretreatment. This study evaluated the effect of initial ripening stage and sucrose concentration of the osmotic solution on physicochemical, optical and mechanical properties of freeze-thawed mango slices during 20 weeks of storage at -18^{o}C. The objective for the second part of this research was to develop a vocabulary appropriate to characterize the sensory properties of frozen mango and use

the generated attributes to assess how treated mangoes were perceived by a trained panel. The objective for the third part was to study the modification of the glass transition temperature (T'_g) obtained though mango pulp formulation with different cryoprotectants on the ascorbic acid during storage. State diagrams and sorption isotherms were determined in order to predict freezing storage conditions for the pulps.

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CHAPTER 2

LITERATURE REVIEW

Mango Fruit

Mango (*Manguifera indica L.*) is the most heavily produced tropical fruit in the world, comprising 40% of the tropical fruit production in 1999 [1]. India, China and Mexico produce mangos in the greatest amounts. This crop is best adapted to a warm tropical monsoon climate, with pronounced dry seasons followed by rain [2]. The mango is native to southern Asia, especially Burma and eastern India. The fruit is grown commercially on a small scale in Florida. In California, a large planting in the Coachella Valley has now reached production stage. The quality of the fruit is generally comparable to Florida mangos, but the area has other advantages, such as the lack of fruit fly and seed weevil populations. Mexico, and to a lesser extent Central America, is a major supplier to U.S. markets today. The flesh of a mango is peach-like and juicy, with fibers of varying amounts radiating from the husk of a single large, kidney-shaped seed. Fibers are more pronounced in fruits grown with hard water and chemical fertilizers. Mangoes are also, high in sugars and acid [3]. Mangoes are highly perishable due to, among other causes, the activity of degradative enzymes (such as polygalacturonase and cellulase), which are activated in the maturation period, causing reduction of nutrients and softening of the fruit [4]. Mango is and one of the most commonly eaten fruits in tropical countries around the world.

Nutritional value

Mango fruit contains amino acids, carbohydrates, fatty acids, minerals, organic acids, proteins and vitamins. During the ripening process, the fruit is initially acidic, astringent, and rich in ascorbic acid (Vitamin C). Ripe mangos contain moderate levels of Vitamin C, and fairly

rich in provitamin A [5]. Fruit acidity is primarily due to the presence of malic and citric acids. In addition, oxalic, malonic, succinic, pyruvic, adipic, galacturonic, glucuronic, tartaric, glycolic, and mucic acids are present [6, 7]. Acidity is cultivar-related. During ripening, acidity decreases to 0.1-0.2%. Following fruit set, starch accumulates in the mesocarp of the fruit. Free sugars, including glucose, fructose, and sucrose, generally increase during ripening; however, the sucrose content increases three- to four-fold due to the hydrolysis of starch [7].

Mangoes show chilling injury symptoms if stored at temperatures below 13^{o}C for several days [8]. To maintain the fruit quality throughout reasonably long periods, controlled atmosphere storage is required [4]. The development of peeling and slicing machines, high capacity pulp pasteurizers, continuous pulp filling units, and aseptic filling systems have improved the efficiency of mango processing [2]. Unfortunately, in many cases this technology is not available in producing countries because the fruit is generally consumed fresh. Methods for maintaining freshness and ensuring a longer shelf life of the mango would be useful for increasing commercialization in producing countries. In general, tropical fruits such as mangos are used in the fruit beverage industry, in the dairy industry as a flavoring ingredient, and in baby food formulations. There appears to be a growing market for individual quick frozen (IQF) mango slices or pieces, which are used in the production of yogurts, bakery products and fruit salads [9]. Physicochemical composition is important in the selection of the cultivar of mango to be processed. Mangos are processed at both unripe and ripe stages of maturity for conversion into a wide range of products (Table 1.1) [2].

Table 1.1 Utilization of mangos for processing [2]

Green mangoes	Ripe mangoes	Waste (peel)	Waste (stone)
Mango pickle	Mango slices in syrup	Pectin	Starch
Mango Chutney	Mango juice	Mango syrup	Fat
Mango slices in brine	Mango nectar Mango pulp	Aroma Concentrate Colorant Biogas	
Dehydrated slices or powder	Mango squash		
Raw mango beverage	Mango beverage Syrup Jam Fruit bars Powder Strained baby food Cereal flakes Concentrate Aroma Structured products		

Mango processing technologies

1. Green mangoes

Green mangos (firm fruit with developed stone, but unripe) are processed into traditional products such as brine stock, pickles, chutneys, and dried powder. Mango pickles are classified as salt pickles or oil pickles [2]. They are processed from whole and sliced fruit, with and without stones [1]. Mango chutney is processed as two types: (i) sweet chutney and (ii) hot chutney. The product is prepared from peeled unripe or semi-ripe fruit [10]. Raw mango slices dried in the sun or using a mechanical drier and powdered is a product called amchur, which is recommended for use as a base material for preparing raw mango drink or thick mango chutney. The powder is a rich source of carbohydrates, acids, minerals, and Vitamin C [2].

2. Ripe mangos

Ripe mangos (mature and post-climacteric ripe fruit with full flavor development) are processed in a variety of forms, such as (i) puree for remanufacturing into products such as nectar, juice, squash, jelly jam, and dehydrated products; (ii) slices which can be preserved by canning or freezing; (iii) beverages that include mango juice, nectar, ready-to-serve beverage, squash, and syrups; (iv) dried or dehydrated fruit in the form of pieces, powders, and flakes; and (v) canned products in slices, cheeks, dices, or purees [2].

Problems in mango processing

Mango processing presents many problems as far as industrialization and market expansion is concerned. The trees are alternate bearing, and the fruit has a short storage life; these factors make it difficult to process the crop in a continuous, regular way. The large number of varieties with their various attributes and deficiencies affects the quality and uniformity of processed products. The lack of simple, reliable methods for determining the stage of maturity of varieties for processing also affects the quality of the finished products. Many of the processed products require peeled or peeled and sliced fruit. The lack of mechanized equipment for the peeling of ripe mangoes is a serious bottleneck for increasing the production of these products. A significant problem in developing mechanized equipment is the large number of varieties available as well as their different sizes and shapes. In addition, the cost of processed mango product is too expensive for the general population in the areas where most mangos are grown. There is, however, a considerable export potential in developed countries, but in these countries the processed mango products must compete with established processed fruits of high quality and relatively low cost [1].

One possible method for processing mango could be osmotic dehydration with sugar solutions while working at mild temperatures to preserve the product flavor and other sensory properties [11]. The major sugar in mango is sucrose [12];therefore, it is to be expected that the osmotic treatments using solutions of this sugar are those which would least alter the sensory properties [4].

Osmotic Dehydration

In recent years, osmotic dehydration of foods as an alternative intermediate step or as a pretreatment technology has received increasing attention in the field of fruit preservation as a means of reducing energy consumption and improving the quality of food products. It gives rise to, at least, two major simultaneous counter-current flows: an important water flow out of the food into the solution and a simultaneous transfer of solute from the solution into the food (Figure 2.1), which are both due to the water and solute activity gradients across the cell membrane [13].

Osmotic dehydration, also known as dewatering impregnation soaking (DIS) [14], uses a sequence of technological steps to achieve controlled changes of the original properties of the raw material [15]. As a result, it is possible to change the food system formulation, making it more suitable for further processing by [16]

- Adjusting the physicochemical composition of food by reducing water content, or adding water activity lowering agents
- Incorporating ingredients or additives with antioxidants or other preservative properties into the food
- Adding solutes of nutritional or sensory interest
- Providing a larger range of food consistency

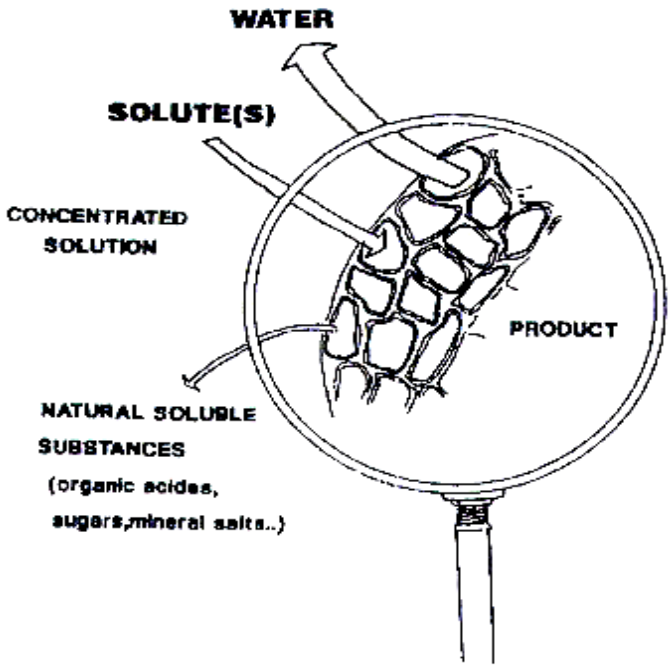

Figure 2.1 Mass transport phenomena during the osmotic process. As Presented by Torregiani, [13].

Osmotic dehydration is a commonly used operation in the processing of fruits and vegetables, and is used to obtain several kinds of products such as minimally processed or intermediate moisture products [17].

History

Research on osmotic dehydration of foods was pioneered in 1966 by Pointing and coworkers [18], and, since then, a steady stream of publications has continued to appear [19]. In their process, the fruit was reduced to about 50% of its original weight by osmosis, during which the fruit was frozen or air-vacuum dried. Farkas and Lazar [20] provided a monograph to predict the osmotic drying rate of apple. Vial and coworkers [21] and Heng [22] studied the osmotic dehydration (kinetics and product quality) of kiwi fruit and papaya in glucose and sucrose syrups. In 1987, Torregianni [23] studied the product stability of osmotically processed cherry by

analyzing ascorbic acid, sugar content, acidity, pH, color, and organoleptic characteristics. Mass transfer during osmotic (sucrose) dehydration of pineapple rings was studied by Beristain and coworkers[24]. Many review articles have already been published [25-27] dealing with various parameters, such as the mechanism of osmotic dehydration, effects on operating variables of osmotic dehydration, as well as modeling of water loss and solid gain [19].

Mechanism of osmotic dehydration

Food can be dehydrated osmotically by immersion in a concentrated solution containing one or more solutes. When used for whole plant tissues, such dehydration is characterized by the large-scale transfer of water through the cell membrane, whereas the transfer of solutes is limited. This behavior is due to the differential permeability of these membranes [28]. This osmotic phenomenon is largely controlled by the plasmalemma, which is the membrane surrounding the protoplast in the cell [29]. Osmosis is the basis of osmotic dehydration. In general, transport mechanisms for the intact cell are still poorly understood. Studies and models considering the selectivity of cell membranes on the transport of solvents in plant tissues have been few in number.

Rotslein and Cornish [30] considered the permeability of cell membranes in the transfer of water during conventional drying of plants. Yao and Le Mager [25, 31] also considered mathematical models to describe transport during osmotic dehydration in plant tissue. For cellular biological materials (Fig. 2.3) [32], it was proposed that the dehydration front (represented by Δx) moves during osmotic dehydration towards the center of the material. This result in cell membrane disruption in the dehydrated region, and the water is transported across three different regions: diffusion of water from the core of the material to the dehydration front, diffusion of water across the front, and diffusion of water through the osmotically treated

material into the surrounding medium. At first, water diffuses from the outer layer of the sample to the osmotic medium, thereby increasing the osmotic pressure at the surface. As the osmotic pressure reaches a critical value, the cell membranes rupture and shrink. This results in a steep reduction in the proportions of the intact cell, which is reflected in an increase of the cell permeabilisation index (*Zp*). *Zp*, is an integral parameter, which indicates the relative reduction in the intact cells. D_3 is the diffusion coefficient of water released through ruptured and shrunken cells into the osmotic solution at any time. As osmotic dehydration proceeds, the dehydration front moves into the product. In this front, the cells are in the process of disintegration, hence the rate of mass transfer increases sharply. At this juncture, a relatively large amount of water diffuses out, with a diffusion coefficient D_2 ($D_2 >> D_3$). As the cells in the core of the material are intact, the diffusion coefficient of water from the core (D_1) is much lower than D_2 and D_3.

Effect of process parameters in osmotic dehydration

Mass transfer during OD is influenced by several factors, including temperature, concentration of osmotic medium, size and geometry of the samples, sample to solution ratio, degree of agitation of the solution, and pre-drying treatments. Temperature is one of the factors which is known to be involved in the rupture of the integrity of plant tissues and membranes; for instance, plasma membranes begin to suffer irreversible damage at 55^{o}C [33]. The rate of dehydration also increases as the level of agitation is increased. An adequate level of agitation ensures minimization or elimination of liquid-side mass transfer effects [19]. Time of exposure affects the behavior of cell membranes. It seems probable that, as time passes, the membranes no longer provide an effective barrier for the solute, which is then free to penetrate in all parts of the cell [34].

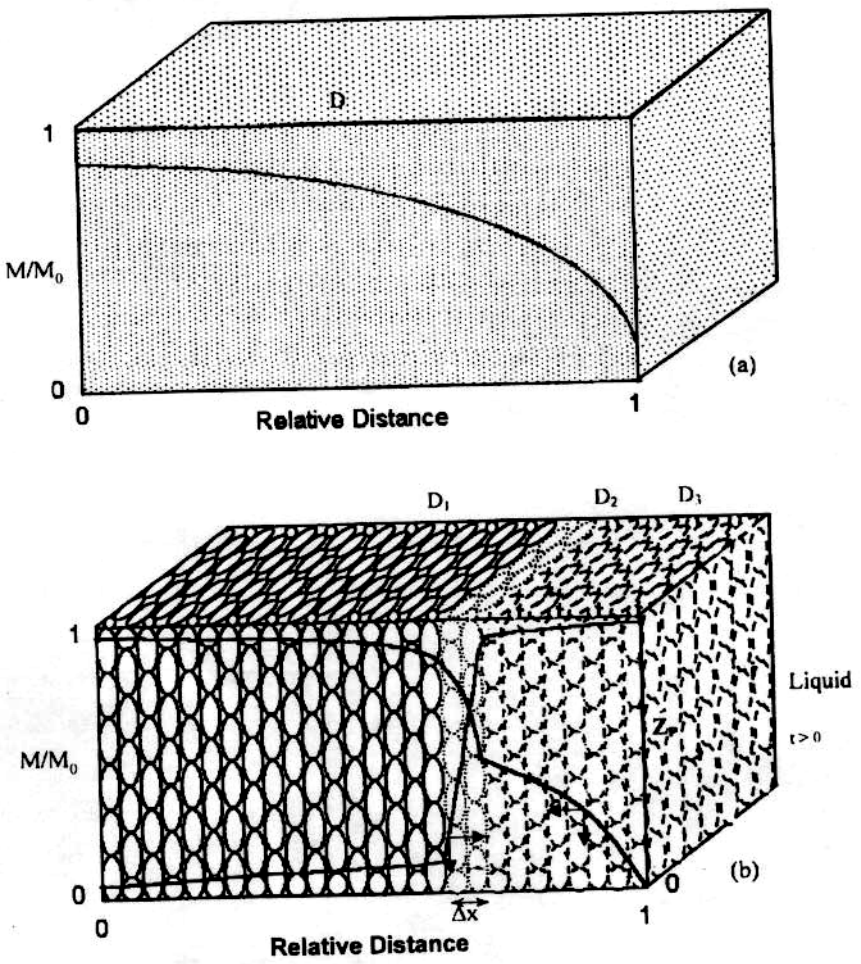

Figure 2.2 Mechanism of osmotic dehydration: (a) non-biological homogeneous material and (b) biological material. *Zp* and M/M_o are the cell disintegration index and relative moisture content, respectively. *D* is the diffusion coefficient of water from homogeneous material during osmotic dehydration. *D1*, *D2*, and *D3* are the diffusion coefficients of water from the core of the material to the dehydration front, across the front, and through the osmotically treated material into the osmotic solution, respectively. Δx is the thickness of the moving dehydration front. As presented by Rastogi [19].

Mass ratio of product plus solution can induce different effects in the solution as the dehydration progresses. The osmotic solution becomes increasingly dilute, and the driving force for further release of water decreases. The shape of the solid material is another important factor in osmotic dehydration. If the solid is bigger in size, it will dehydrate more slowly because the length of the diffusion path is greater. Food structure (porosity of the tissue), nature and molecular weight of the osmotic solute, and pressure (high pressure, ambient or vacuum) can also influence mass transfer during this process [19].

Osmotic dehydration implementation problems

The implementation of osmotic treatments (OT) of plant or animal materials in concentrated solutions presents a critical factor due to the management of the concentrated sugar/salt solutions. The main problem in managing the osmotic solution is the dilution rate. The food/solution ratio must be controlled in order to assure a constant rate of water/solution exchanges [35]. Different technologies to maintain high food/solution ratios have been patented [36, 37]. These technological approaches involve spraying of solution on the food; as the treatment continues, the treatment solution is collected and recycled.

Another problem related to implementation of osmotic treatments in the industry is the loss of solutes and particles from fruits, such as, aromas, pigments, acids, and proteins, which are leached into the solution. All these transfers lead to chemical modification of pH, water activity (*aw*) as well as physical (viscosity) and sensorial (color and flavor) changes during utilization [35]. Restoration of solute concentration must be controlled when the solution is recycled. Several methods have been proposed to achieve this goal, including evaporation (both atmospheric at high temperature or under vacuum at low temperature), solute addition (saving energy costs by avoiding both heat of evaporation and the need for expensive plants), membrane

concentration, and cryoconcentration. Microbial contamination by yeasts, molds, and lactic bacteria is most common during fruit and vegetable processing. Individualization of critical control points (CCP) and implementation of HACCP methodology for process control become needed when the osmotic treatment process is carried out without any subsequent process set up to obtain the final stabilization of the product [35, 38, 39].

Previous studies related to osmotic dehydration of mangos

Physiology of mango slices subjected to osmotic dehydration was studied by Tovar and coworkers [40, 41]. The effect of a 30-min osmotic dehydration treatment under vacuum and storage temperature was evaluated. The respiration rate of treated and non-treated slices was measured. The synthesis of 1-aminocyclopropane-1-carboxylic acid (ACC) indicated activity of the samples. ACC activity was associated with enhanced membrane stability. Results suggested that osmotic dehydration was beneficial as a pre-treatment for mango slices in bringing about longer shelf life during refrigeration. Titratable acidity, pH, and soluble solids were measured also. The study concluded that osmotic dehydration causes decreased alterations in organic acid balance, and a concomitant increase in soluble solids. In other study, the effects of previous blanching and osmotic dehydration (at atmospheric pressure and in vacuum) with glucose syrups on the kinetics of water transport during the first falling rate period of air drying of mango at 60^{o}C was investigated [42]. The applied pretreatments affected the course of drying. Osmotic dehydration adversely influenced the drying rate, this effect increasing as glucose concentration of the impregnation solution increased. Tedjo and coworkers [43] compared mass transfer during osmotic dehydration and some quality indices of untreated mango to those pretreated by applying high intensity electric field pulses (HELPs), high pressure (HP), or supercritical carbon dioxide having the same initial disintegration index (Z_p) in the range 0.50-0.58. The results of

this study suggest that the influence of cellular integrity on the diffusion kinetics of mangoes may be twofold. In this study, the type of pretreatment had a great influence on the solids gained. The application of supercritical carbon dioxide enhanced solid gain during OD, but minimized water loss. The application of HELPs increased water loss during OD, minimizing solid gain. Mango, apple, and melon where used to study the effect of the vacuum pressure (135-674 mbar) and syrup concentration (41-60^{o}Brix) during osmotic dehydration [44]. The results reported that water loss of similar magnitude was observed in melon and mango, and there was a water gain in the case of apple. On the other hand, solid gain was less in melon and mango than in apple.

The influence of sucrose solution concentration (osmotic agent) (35, 45, 55, and 65^{o}Brix) and vacuum pulse application (50mbar for 10 min) on kinetics and yield of the osmotic process was analyzed by Giraldo [4] and coworkers. The study was focused on the ratio of water-loss-sugar gain throughout the process and its influence on product mass and volume losses. Results suggested that mass transport properties of mango tissue were greatly affected by sucrose concentration and by vacuum impregnation of the sample at the beginning of the process. Tissue impregnation with 45^{o}Brix sucrose solution showed very high sugar gain-water loss ratios. The treatment was recommended for mango candying processes.

The effects of vacuum pressure (135-674 mbar) and its application time on the volume of isotonic solution impregnated in slices of mango, apple, papaya, banana, peach, melon, and mamey were studied using response surface methodology [44]. Vacuum pressure had a significant effect on maintaining the volume and shape of all impregnated fruit slices, depending on their porosity. A study on the effects of syrup concentration (30-70^{o}Brix), solution temperature (22-90^{o}C), and sample geometry (cube, slice, and wedges) on equilibrium distribution coefficients of mango was investigated during osmotic dehydration [45]. The

distribution coefficient for water decreased with increasing temperature and surface area, and increased with an increase in syrup concentration and thickness of the minimum geometric dimension. The distribution coefficient for solids increased with an increase in temperature and surface area, while it decreased with an increase in syrup concentration and thickness of the minimum dimension.

Sensory Quality of Fruits

Quality of fresh cut fruit and vegetable products consists of a combination of attributes, properties, or characteristics that determine the value of the products to the consumer. Fruit quality characterization is performed on the basis of physical and chemical properties. Shape, size, color, and gloss are appearance quality factors associated with visual defects in the fruit. Undesirable changes in firmness, crispness, juiciness, and toughness are textural quality factors associated with loss of integrity, and are a cause of poor quality. Sweetness, sourness, astringency, bitterness, aroma, and off-flavors are flavor quality factors associated with perception of tastes and aromas of many compounds. Vitamins, minerals, and dietary fiber are nutritional quality factors associated with nutritional losses. These properties are directly correlated with fruit utilization [46]. Both pre-harvest and post-harvest factors influence fruit quality. A combination of preservation factors can be applied in order to obtain a more stable product with a shelf life of several weeks or months, instead of a perishable one that has only a short shelf life at chilling temperatures [47].

Sensory evaluation is critical to understanding and monitoring flavor and texture changes. Such analysis can be expensive, but it is essential in understanding what is happening in the mouth and nose before a correlation with instrumental methods should be attempted. This can be used for quality assurance and quality control purposes, but instrumental methods, if available,

are more economical on a routine basis. Consumer-based evaluations are subjective and depend on a pool of consumers being tested. Flavors of fruits and vegetables are unique. Some flavor characteristics are, however, common among fruits and vegetables. Flavors common in many fruits are caramelized/honey, chemical, as well as estery, fruity and floral, or perfumy. Off-flavors common in fruits are deteriorated/rotten and fermented [46]. Texture, as opposed to flavor, is the structure and orientation of food as well as the reaction of the food to an applied force. The texture attributes can be divided into four areas: surface properties, first bite properties, chew down, and after swallowing properties [48]. Some of the overall most important attributes are crispness, hardness, and juiciness or moisture release [46].

Factors that affect fresh-cut sensory quality of fruits have been noted. For example, cultivar differences can have significant effects on flavor and texture. Cultural and environmental conditions (climate, fertilizer application, soil conditions) can also cause changes in a given cultivar which could affect flavor and texture. In addition, crop maturity has a significant impact on the quality of fresh-cut produce. Immature fruit tend to get harder during storage than mature fruit. Cutting the fruit typically causes the respiration rate to increase. Therefore minimal cutting is better for shelf life since it keeps the respiration nearer to that of intact produce. The processing environment is another factor that must be controlled, because it is critical to flavor and texture quality. Usually the room temperature should be maintained at 2.8^{o}C [46]. Cleaning of the contact surfaces as well as personnel precautions should be taken to minimize microbial problems. Browning of fruit, usually caused by oxidation of phenols catalyzed by polyphenol oxidase enzymes, can alter flavor and texture dramatically. Packaging selection should take into account the selection of a permeable film to retard or to enhance chlorophyll degradation, control browning, and delay bacterial and mold growth. Finally, a

proper storage temperature assures minimal changes to flavor and texture of the product. Very high temperatures can cause microbial spoilage and the development of off-flavors. On the other hand, very low temperatures can cause chilling injury, which weakens tissues and causes internal discoloration of the fruit [46].

Flavor is considered a consumption attribute critical to consumer acceptability of mangoes [49]. Organic acids and sugars are key components in the perception of mango flavor [49]. The major sugar in mango is sucrose [12], and, therefore, it is to be expected that osmotic treatments using solutions of this sugar are those which alter the product the least [4]. There is often a decrease in the quality of dried products since most conventional techniques use high temperatures during the drying process. Processing may also introduce undesirable changes in appearance, and will cause modifications of the natural flavor and color of the fruit. However, these changes are not consistent with the increasing demand of consumers for the highest quality finished products. Therefore, some dehydration techniques for fruits are focused on the production of dried products with little or no loss in their sensory characteristics [50].

Freezing

Frozen fruits constitute a large important food group in modern society. Fruit may be more extensively used if available during the off season. In addition, frozen fruit can be transported to remote markets that could not be accessed with fresh fruit [51]. Although freezing of fruits results in improved effects with respect to shelf life and availability throughout the year, various undesirable changes occur as a result of this process [52]. Freezing is damaging for a number of reasons. In particular, cells rarely survive intracellular ice formation (IIF). When an aqueous solution freezes, the remaining unfrozen water is the solvent for all solutes, at concentrations that become very large as temperature falls. These concentrations may be

detrimental to cell function. High concentrations of electrolytes affect ionic interactions, including those that help stabilize the native state of proteins. Unfolding and denaturation of proteins is often irreversible. Further, ice and water interact differently with hydrophobic surfaces [53]. Mechanical damage from ice crystals occurs when flexible cell components are stressed in areas where ice is present. During frozen storage, crystals undergo metamorphic changes because systems tend to move toward a state of equilibrium where free energy is minimized. Ice crystals continue to grow in size, and they exert additional stresses to the cell membrane [54].

Damage to the membrane can be attributed to different events within the tissue, depending on the rate of freezing. Commercial freezing of foods would generally be considered rapid freezing. Damage in this case can take different forms; for example, toxicity due to concentration effects [55], or damage to structures within cytoplasm. Membranes of cytoplasmic organelles are vulnerable to loss of membrane functionality due to irreversible endocytic vesicles [56], lamellar to hexagonal transitions [57], membrane aggregation due to a reduction in charge density, and a reduction in free sterol content of membrane lipids [58, 59]. Freezing causes severe changes in product macroscopic properties. It causes a dramatic texture loss due to cryoconcentration phenomena, which promote membrane denaturation and cell wall degradation mechanisms, and, in turn, the mechanical stress which is provoked by increased ice formation induces membrane rupture. The membrane rupture results in enzyme and/or chemical activity, and also contributes to mechanical damage [60]. Osmotic dehydration as a pre-freezing treatment has been reported to reduce these changes, contributing to an improvement in the fruit quality [61, 62]. During storage, foods are not completely frozen and will continue to deteriorate.

Freezing is very destructing to tissue cells or anything else containing water because it expands when it freezes [54].

Osmotic dehydration as a pre-freezing technique

The frozen fruit industry uses much energy in order to freeze the large quantity of water present in the fresh product. A reduction in moisture content of the material reduces refrigeration load during freezing [63] [13]. Other advantages of partially concentrate fruits prior to freezing include savings in packaging and distribution costs and achieving higher product quality because of the marked reduction of structural collapse [13]. It has been proven that osmotic treatment improves the texture characteristics of thawed fruits and vegetables [64, 65], decreases enzymatic browning [61], and reduces structural collapse and drip loss during thawing [62]. Fruit pre-treatment by osmotic dehydration before freezing (osmodehydrofreezing) has been reported as a tool in fruit cryoprotection, mainly due to the reduction of freezable water content or to the possible specific function of determined impregnated solutes in membrane protection [65, 66].

Water Activity and Food Preservation

Water activity (a_w) is defined as the vapor pressure of the food (p) divided by the vapor pressure of pure water (p_o) at the same temperature [50]. Relative vapor pressure could be in some cases more important to the quality and stability of food than the total amount of water present. Water activity (a_w) is chosen over moisture content (MC) as the reference parameter in most applications of food processing and storage based on a number of reasons, such as that a_w is the determinant for the growth of certain microorganisms. Also, a_w is well related to most degradation reactions of a chemical, enzymatic, and physical nature. The 'monolayer' derived from water vapor sorption isotherm gives an indication of the optimum moisture content in dried foods. Water can react in foods in different and complex ways, such as hydration of polar or

ionic groups, reactions caused by dissolution of chemical species, increasing the plasticization effect (diffusion of reactants), and decreasing the reactant concentration at high water contents. Also, water itself can act as a reactant or be a product of the reaction such as in maillard browning [67].

Sorption isotherm

The sorption isotherm is an extremely valuable tool for the food scientist because it can be used to predict potential changes in food stability. It can also be used for packaging selection as well as for ingredient selection [68]. Sorption isotherms describe the relation between the water activity and the moisture content, and are normally determined by storing dried samples over saturated salt solutions and measuring the steady-state water content. In Figure 2.3, *A* represents the sorption of water molecules onto the sorbent binding sites [69]. Region *B* corresponds to the sorption of additional layers over the monolayer. Over the region *B*, water clusters begin to form, in which the attraction between water molecules is stronger than that between water molecules and active sites [70, 71]. In the capillary condensation region (*C*), water condenses in the porous structure of the food systems and acts as solvent for various solutes [71].

There can be considerable hysteresis between the adsorption isotherm and the desorption isotherm, which is mainly due to the non-existence of equilibrium of the vapor pressure inside a food and its surroundings [50].

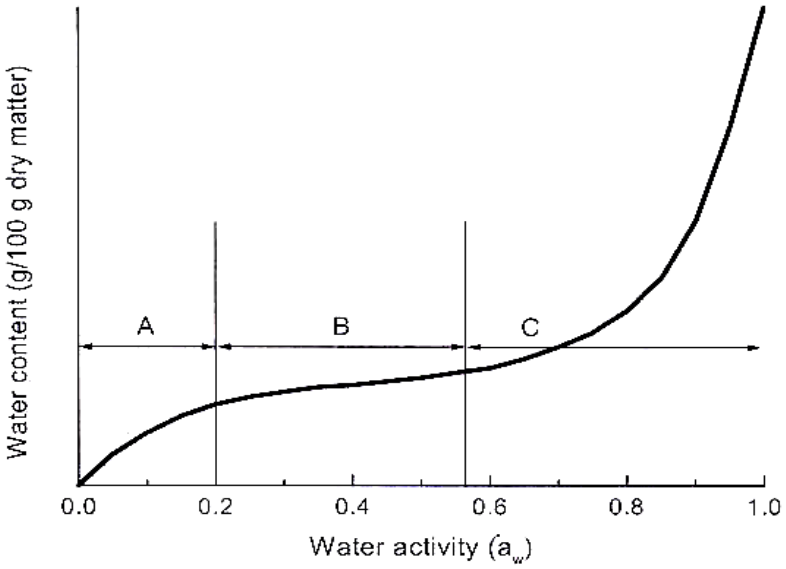

Figure 2.3 A typical moisture isotherm for most food materials. As presented by Laaksonen [71].

Studies on the rates of chemical reactions in foods have shown that for most dry foods a moisture content exists, below which the rates of quality loss are negligible. This moisture content corresponds fairly well with the monolayer value [72], as determined from the Brunauer-Emmet-Teller (BET) isotherm equation or Guggenheim-Anderson-de Boer (GAB) isotherm equation described elsewhere [68]. The GAB isotherm is more useful, because it has been shown to fit experimental sorption data over the whole a_w range [71, 73], whereas the BET isotherm fits only over the narrow experimental sorption data range (between 0 and 0.4 a_w) [71]

Glass Transition Temperature

Frozen and freeze-dried food materials behave like highly viscous materials of low density bulk structure with either "rubber" or "glass" characteristics, depending on the final temperature and moisture content [74]. The glass transition temperature, T_g, is the temperature at which supersaturated solution converts to a glass [75]. A glass is a non- equilibrium, metastable,

amorphous solid of extremely high viscosity, i.e., 10^{10}-10^{14} Pa. The formation of a glassy supersaturated state in frozen materials is achieved by the removal of large quantities of water by the process of freeze concentration, since water is a readily crystallizable plasticizer [76, 77]. The T_g is dependent on solute type and water content. T_g' is a special T_g that applies only to samples containing ice, and only when ice has been formed so maximally-freeze concentration occurs (very slow cooling) [75]. No further unfrozen water is unable to crystallize below T_g', and thus, depending on the viscosity in the vicinity of T_g', the ice melts at the same temperature.[78].

Effect of T_g on physical properties of food materials

Within the unfrozen, freeze-concentrated phase, translational mobility decreases to a point where the molecules are unable to achieve their equilibrium conformation and packing [79]. Dehydrated low moisture and frozen foods are typically in an amorphous metastable state, which is very sensitive to changes in moisture content and temperature. The transition from the liquid state to the glassy state is characterized by discontinuities in certain physical properties, such as coefficient of expansion, free volume, dielectric constant, and viscosity, while other properties change [80, 81]. Figure 2.4 summarizes these changes.

The rate at which chemical reactions occur in frozen foods is a main determinant of the quality of the food after frozen storage. Oxidation of ascorbic acid, degradation of lipids and precipitation of proteins are examples of reactions which decrease the quality of such foods [82]. The retention of ascorbic acid in frozen foods is known to be highly dependent on the storage temperature and has been shown in model systems, also on the presence of glass forming substances.[83]. Rate enhancement in frozen cellular material is a consequence of cell membranes being disrupted by changes in osmotic pressure, pH, and salt concentration, which allows for substrate-enzyme interaction [84]. Factors such as variety, maturity, growing area and

seasonal variations influence frozen storage performance of fruits to an extent that may override the positive effect of a high freezing rate. The most important effect of glass transition on physical properties of food materials is the increase in mobility in the rubbery state, which affects various physical and chemical deteriorative changes [78, 80, 85]. Many amorphous foods must be processed and stored in their glassy state to avoid deterioration [78].

Methods for determination of T_g

Since glass transition manifests itself as a change in thermal and mechanical properties, thermal analysis techniques are most commonly used to study this phenomenon [86, 87]. In particular, measurement of the change in heat capacity (*Cp*) using differential scanning calorimetry (DSC) (Fig. 2.5) has become the established method, largely because of its ease of operation and widespread availability.

Because T_g is a time and frequency dependent phenomenon (occurs over a temperature range), dielectric analysis (DEA) as well as other spectroscopic methods, such as NMR and electron spin resonance (ESR), are also useful since they allow for the measurement of relaxation times more applicable to time/frequency materials [87]. It must be kept in mind that the glass transition temperature measured by different methods does not yield equivalent values. Hence, it would be erroneous to compare the results of one experimental technique with those of another [81].

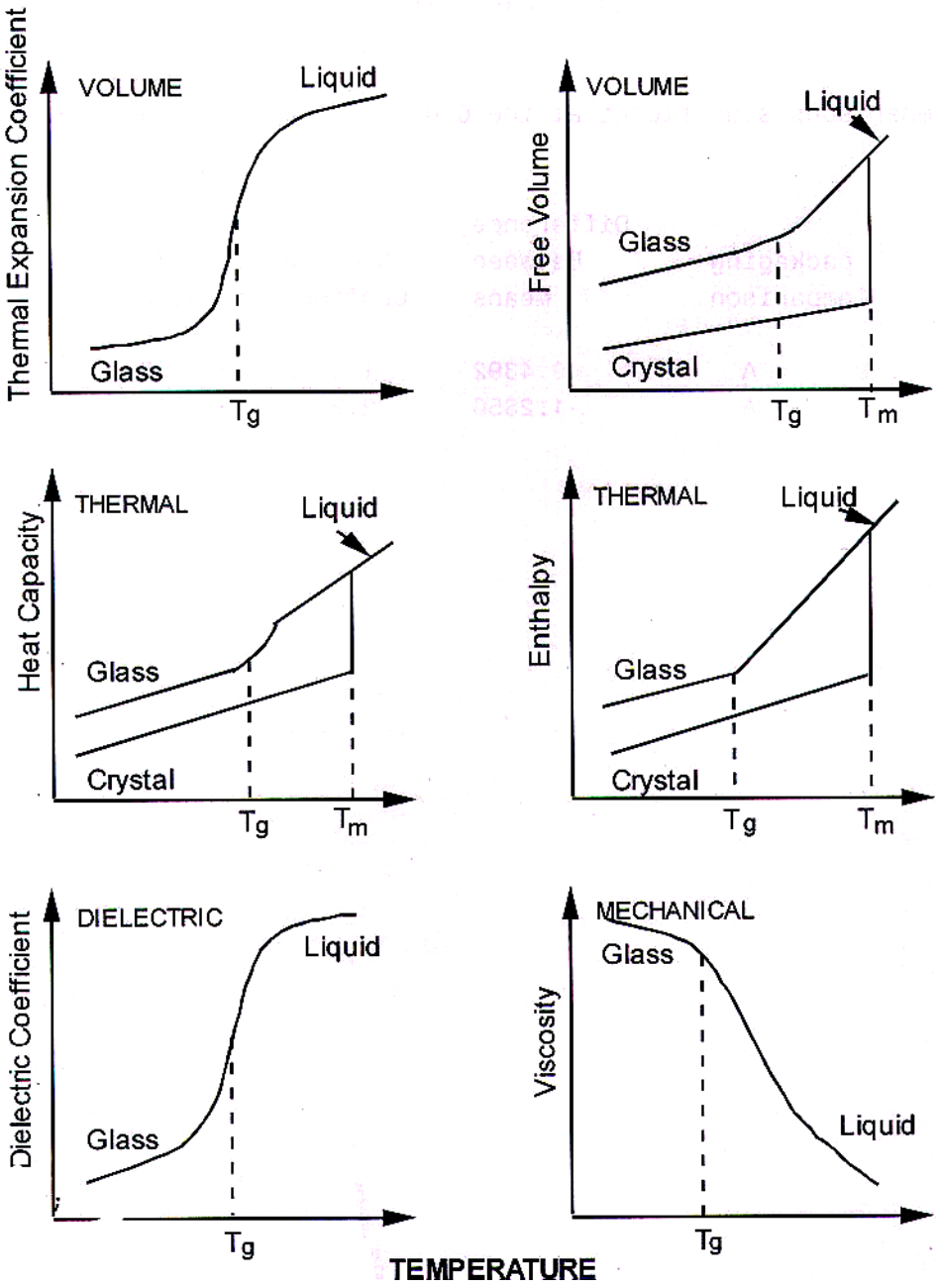

Figure 2.4 Characteristics of transition from liquid to glass. (a) Coefficient of expansion (b) Free Volume (c) Specific heat (d) Heat content (e) Dielectric constant (f) Viscosity As presented by Vanchy [81].

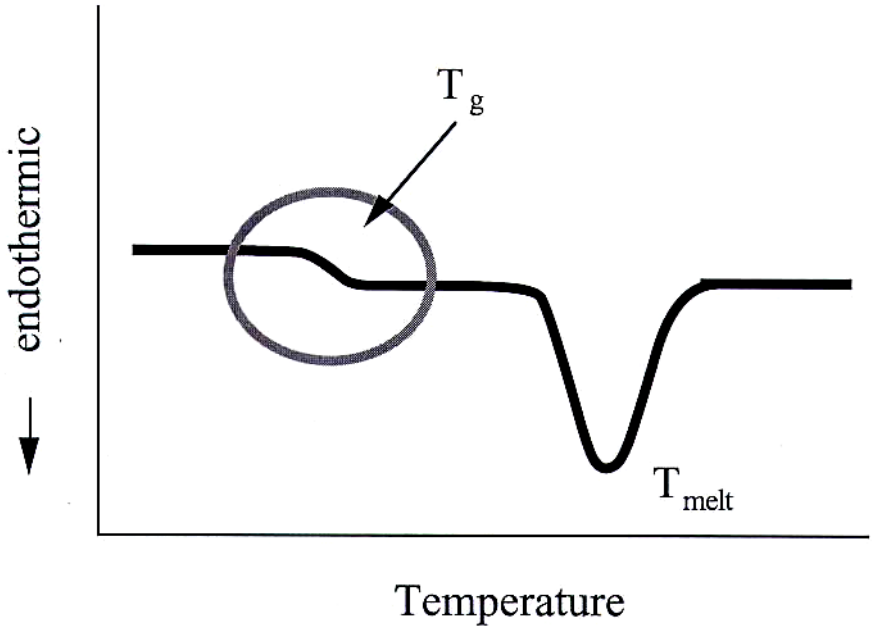

Figure 2.5 DSC Thermogram. As presented by Labuza [88]

Water Plasticization of Food Components

Water is a plasticizer of great effectiveness and it greatly affects T_g. Plasticization could be explained as an increase in the free volume of the amorphous matrix, which enhances mobility of the polymer chains. Plasticizers perform their role by reducing the glass transition temperature of the material. Water, because of its small molecular mass, can remain surprisingly mobile within a glassy matrix. This plasticizing action results in enhanced molecular mobility both above and below T_g. As water increases, T_g decreases and free volume increases. This occurs because the average molecular weight for the mixture decreases. In general, T_g decreases about 5-10^{o}C per water total percentage (wt%) added [75]. Water plasticization also decreases crystallization temperatures of amorphous crystallizable materials and the melting temperatures of the crystals [78].

Prediction of Tg Using Mixing Equation

There are several models describing plasticization in food polymers. The most commonly used is the Gordon-Taylor equation [81, 89]. This equation (Eqn. 1) has been used to predict *Tg* in maltodextrins plasticized by maltose [90].

$$T_g = \frac{w_1 T_{g1} + k w_2 T_{g2}}{w_1 + k w_2} \qquad \text{Eqn. 1}$$

Where, T_g = glass transition temperature of mixture containing solids and water

T_{g1}, T_{g2} = T_g of pure dry solids and pure amorphous water, respectively

w_1 = weight of fraction of solids

w_2 = weight of fraction of water

k = constant

Theoretically, the glass transition temperature of water is reached as the weight fraction becomes one. However, water in food and other biological materials is a crystallizable plasticizer, and the more concentrated the system studied, the lower is the melting or freezing temperature of water. In foods, crystallization of water leads to freeze concentration of the food solids, and thus to a gradually decreasing melting point and eventually to a constant T_g of the unfrozen matrix, which remains at a constant solute concentration [78].

Prediction Using Tg at Varying Relative Humidities

At low and intermediate moisture contents, the T_g values of amorphous food materials are decreased linearly with the increasing water activity. This linear relationship is of practical importance since it allows the prediction of glass transition temperatures for materials exposed to various relative humidities [74] [91] [78].

Cryostabilization technology

Cryostabilization technology emerged from food polymer science research and developed from a fundamental understanding of the critical physicochemical and thermo-mechanical structure-property relationships that underlie the behavior of water in all non-equilibrium food systems at subzero temperatures. Cryostabilization provides a means of protecting products, stored for long periods at typical freezer temperatures (e.g., -18^{o}C) from changes in texture (e.g., 'grain growth' of ice, crystallization), structure (e.g., collapse or shrinkage), and chemical composition (e.g., enzymatic activity and oxidative reactions, such as, fat rancidity, and flavor/color degradation) [92].

The key to cryoprotection lies in controlling the physical state of the freeze concentrated amorphous matrix surrounding the ice crystals in a frozen system, in which deteriorative reactions mainly occur. This control can be exerted by regulating the physicochemical and mechanical properties of this matrix. There are two possible methods that can be used to achieve adequate food cryoprotection [93]. One is reduction in the water content of the product to below the content of unfrozen water in the frozen product, allowing complete vitrification, by means, for example, of osmotic dehydration with cryoprotectant solutions [94, 95]. This technique is known as dehydrofreezing, and the concentration step is generally performed via air drying, osmotic dehydration, or a combination of both [92]. Another is the formulation of food with appropriate ingredients to elevate the glass transition temperature (T_g) relative to freezer temperature, thereby enhancing the product stability [96].

The effect of molecular weight of polymers on glass transition has been studied extensively [97]. It has been shown that the glass transition temperature increases with increasing molecular weight. On the other hand, addition of low molecular weight components should

increase the free volume, thereby reducing the glass transition temperature [76]. Cryoprotective agents are also thought to lower intramembrane stresses [57, 59, 98] and inhibit protein denaturation in membranes [59, 99]. The molecular weight of amorphous carbohydrates and other components in the food is not the only factor influencing the T_g. The chemical structure of the sugar also plays a crucial role. This would explain the difference in T_g values among isomers such as dry sucrose (62^0C) and dry lactose (101^0C), which have the same molecular weight [81, 100].

State Diagrams

State diagrams contain equilibrium information as well as information on conditions of non equilibrium and metastable equilibrium states. These diagrams show curves showing transition temperatures (e.g., glass transition and melting) plotted against moisture content [75]. State diagrams may be experimentally determined by differential scanning calorimetry (DSC) [101]. A typical state diagram (Fig 2.6) of sugar-water mixtures (as a model for the water phase of fruits) shows that the glass transition temperature decreases with increasing water content; water acts as a plasticizer/softener for sugars. Drying of foods is a way to increase glass transition temperature. Sugars, in their turn, can act as plasticizers for higher molecular weight carbohydrates.

The glass transition temperatures of anhydrous carbohydrates increase with increasing molecular weight, which provides a tool for manipulating the glass transition temperature of food products, i.e., increasing the transition temperature by adding high molecular weight carbohydrates [90]. Consider the freezing of a 20% sucrose solution (large aqueous phase), containing a theoretical T_g close to that of water (-135^{o}C). The initial T_g of this solution at room temperature before phase separation is marked as *A*. As ice crystallization proceeds, the

continual increase in solute concentration (removal of plasticizer) further depresses the equilibrium freezing point of the unfrozen phase in a manner which follows the liquidous curve (Shown as *B* in Fig 2.3), while the T_g of the system moves up the glass transition line with a rapid increase in viscosity [90].

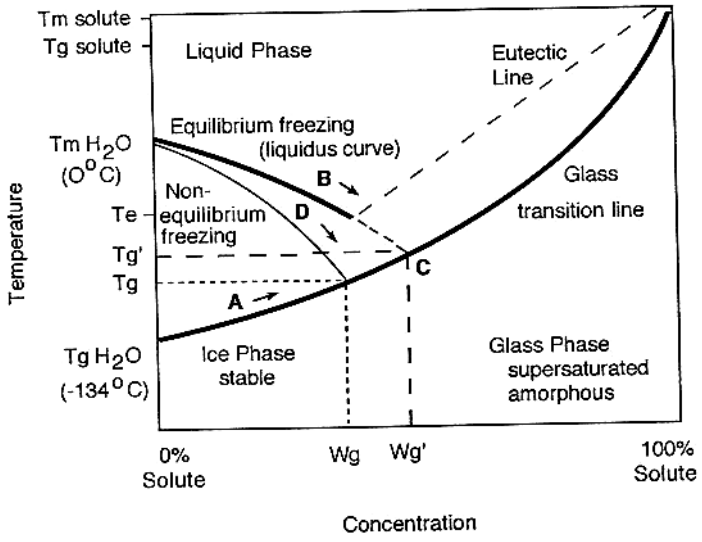

Figure 2.6 State diagram for an aqueous sucrose solution showing the glass transition line, liquidous curve, theoretical eutectic line, and the various physical states defined within the boundaries. As presented by Goff [87].

Assuming equilibrium freezing conditions are satisfied, which is unlikely for the freezing of real food systems, the T_g continues to increase with increased ice formation, and the system becomes supersaturated beyond the eutectic curve. When a critical, solute-dependent concentration is reached, the unfrozen liquid exhibits highly resistant mobility, and the physical state of the unfrozen phase changes from viscoelastic "rubber" to a brittle amorphous solid.

Using Fig 2.6, the intersection of the non-equilibrium extension of the curve and kinetically determined non-equilibrium glass transition curve, denoted as *C*, represents the solute-specific, maximally freeze concentrated T_g of the frozen system, denoted T_g', where ice formation ceases within the time-scale of the measurement. The corresponding unfrozen water content (W_g)' and the composition of the glass (C_g) define the maximum amount of plasticizing water unable to crystallize within the glass and sucrose concentration of the glass, respectively. The typical pathway a system may follow during non-equilibrium freezing is shown in Fig 2.6 as the line leading to lower T_g (*D*) then T_g', with a corresponding lower C_g due to excess undercooled water plasticized within the glass (Goff and Sahagian, 1996). If a glass of concentration equal or higher than C_g' is stored above T_g', several collapse phenomena can occur. It can become sticky and will go through structural transformations such as collapse of the physical structure and crystallization, which results in a release of encapsulated compounds such as flavors [102].

Physical and structural changes affecting quality and stability of processed fruit and vegetables are strongly related to the glass transition temperature, and may occur when T_g drops below the storage or processing temperature, with a rate depending on the difference, T-T_g. For such changes, state diagrams become an elective tool for prediction, while a 'critical a_w' may be identified as an operative parameter from a diagram relating sorption isotherm with glass transition curve [102]. The T_g line on the state diagram poses an upper limit, below which physical changes are avoided. Fruits and fruit-pieces are frequently used as basic materials or additional components in many composites and food formulations. In such systems, the water activity of the ingredients must be controlled in order to avoid moisture migration. For use as ingredients, the fruit a_w is usually reduced by controlled dehydration; however, below a critical

value, excess hardening generally occurs. An alternative is to depress the water activity by an osmotic treatment [64]. For water activities below 0.9, the combination of osmosis and limited air dehydration is usually the best choice [103].

By combining the information from sorption isotherms (water activity versus moisture content) and state diagrams (glass transition temperature versus moisture content/sugar content) it is possible to construct food stability maps. These maps are useful in determining storage conditions for foods at which glass transitions are avoided, or in determining how far a product should be dried in order to keep it under given storage conditions [50].

Other Studies Related to Glass Transition Measurements in Fruits

Differential scanning calorimetry (DSC) was used to measure phase transitions and unfreezable water in fresh samples of onion, grapes, and strawberry after equilibration at different relative humidities in a study by Sa and Sereno [104]. The purpose of the study was to determine phase transitions and other properties of some fruits and vegetables, either fresh or after freeze drying, at different moisture contents. The authors found that it was possible to determine reproducibly the glass transition temperatures and associated phase diagrams for those products, and annealing was necessary to achieve maximum ice formation as well as to obtain meaningful values of T_g'. The effect of the modification of the glass transition temperature through an osmotic pretreatment on the ascorbic acid retention and on the color stability during storage at -20^{0}C was analyzed [105]. The incorporation of different sugars into the apricot cubes was found to modify the percentage distribution of the sugars and their low temperature phase transitions, as well as the ascorbic acid retention during air-drying and the color stability during storage. In 1998, Nijhuie and coworkers [50] reported the effects of dehydration on fruits and vegetables; the role of T_g on the quality and shelf life of dehydrated foods was described. Del

Valle and coworkers [106] studied the relationship between shrinkage during drying and glass rubber transitions of apple pieces.

Osmotic dehydration with aqueous solutions of the same molecular weight but different glass transition temperatures was applied as a pretreatment to increase T_g value. It was concluded that osmotic treatments offer some protection against shrinkage during air drying at high solute concentrations. differential scanning calorimetry (DSC) was used to measure glass transitions in samples of Golden Delicious apples after freeze drying and osmotic drying in sucrose solution [107]. Dehydrated samples were equilibrated under a wide range of different relative humidities (a_w = 0.12-0.93) and sorption isotherms were determined. The isotherms were consistent with similar curves reported in the literature. The glass transition temperatures were reproducible, and the empirical Gordon-Taylor equation was able to predict the dependence of T_g on moisture content.

Osmotic dehydration of apples in concentrated sucrose solutions was carried out to determine mobility changes of water by measuring the NMR relaxation times. Also, thermal analysis of the samples using DSC was used to determine how much water was still present unfrozen at low temperatures. This work was used of NMR in this process. It was possible to determine a strong decrease in water mobility, as more sucrose migrated into the fruits and some physical alterations of the cells due to processing. Sobral and coworkers [108] studied phase transitions of freeze dried persimmon over a large range of moisture content using DSC. This method proved to be adequate for determining the glass transition temperatures in the fruit, allowing for the production of a state diagram for the samples. The Gordon-Taylor model could adequately represent the sugar matrix transition curve. The influence of ripeness and air temperature on changes in banana during drying was studied by Boudhrioua [109]. This study

made it possible to determine parameters which discriminated between degrees of fruit ripeness. A radical change in the rheological behavior of the slices depending on the ripeness of the fruit was demonstrated; the slices lost their deformability and became brittle. A dynamic thermal analysis reported that this abrupt change was related to the product going below the glass transition temperature as it is cooled after drying.

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CHAPTER 3

INFLUENCE OF OSMOTIC DEHYDRATION, RIPENESS AND FROZEN STORAGE ON PHYSICOCHEMICAL, OPTICAL AND MECHANICAL PROPERTIES OF MANGO[1]

(*Manguifera Indica, L.*)

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ABSTRACT

The effect of osmotically dehydrated different ripeness (hard, medium and soft) mango slices immersed in syrups with different concentration of sucrose (0-30^{o}Brix) and stored at -18^{o}C during 20 weeks was evaluated. Physicochemical, textural and optical changes were observed for osmotically concentrated slices compared with fresh samples. Water content reduction and sugar gain had some protective effect against damages caused by freezing during storage depending on sucrose concentration. Slices with higher soluble solids content and lower moisture content provided better protection showing no significant changes ($P \leq 0.05$) for vitamin C, titratable acidity lightness (L^{*}), and some textural parameters such as firmness, cohesiveness and springiness.

Keywords: Mango, Osmotic Dehydration, Quality, Frozen Storage, Ripeness, Thawing

Introduction

There is a large demand for high-quality fruit ingredients suitable for use in many formulations, such as pastry, confectionery products, ice cream, frozen desserts and sweets, fruit salads, cheese, and yogurt. However, to be suitable for these uses, fruit pieces must have natural color and flavor [1]. Proper application of 'combined processes' may fulfill these specific necessities [2]. These processes use a sequence of technological steps to produce controlled changes of the original properties of the raw material [1]. Osmotic treatments involve the contact of a material, usually vegetable or animal in origin, with a concentrated aqueous solution. In addition, they consist of simple food processing operations conducted at ambient or near ambient temperatures, which achieve a significant degree of dewatering without phase change [3]. Although some treatments, such as blanching, pasteurization, and freezing, have a primarily stabilizing effect, other steps, such as partial dehydration or osmotic dehydration, allow the properties of the material to be modified without affecting its integrity [2, 4]. Mass transfer rates of osmotic treatments are influenced by several factors, including temperature, concentration of osmotic medium, size and geometry of the samples, sample to solution ratio, degree of agitation of the solution, and pre-dying treatments [5].

Frozen fruits constitute a large and important food group in modern society. However, fruit may be more extensively used if available during the off-season. In addition, frozen fruit could be transported to remote markets that cannot be accessed by transporters of fresh fruit. Although freezing of fruits results in favorable effects with respect to shelf life and availability throughout the year, various undesirable changes also occur during this process [6]. Freezing of fruits can result in reduced quality, due mainly to adverse effects on texture and retention of enzymatic action [7]. The primary factors that limit the storage life of frozen fruits are color,

texture and flavor changes[8]. Fruit pre-treatment by osmotic dehydration before freezing (osmodehydrofreezing) has been demonstrated to be a useful tool in fruit cryoprotection, mainly due to the reduction of freezable water content or to the possible specific function of impregnated solutes in membrane protection [9, 10]. In addition to removal of water and a subsequent reduction in ice formation, osmotic dehydration using selective solutes can allow cryoprotection of the cell during freezing/thawing.

The mango is an important tropical and subtropical fruit, and is commonly preserved in the dried form in Asia. Both conventionally dried mangoes and frozen mangoes have undesirably tough texture, poor color, and cooked flavor, along with a loss of nutritive value, which reduce their economic importance [11]. Osmotic dehydration of foods has attracted rising interest due to its low temperature (minimal heat damage) and energy requirements. The influence of osmotic dehydration on mangoes has been studied [4]. However, much of the work has focused on the kinetics of solute/water exchange in and out of tissue foods [12], vacuum pulse application during osmotic treatments[13] [14], and effects based on impregnation time[14].

The objectives of the present work are, primarily, to minimize the adverse effects of freezing in mangoes using osmotic dehydration as a pretreatment in order to obtain high-quality frozen mango fruit displaying fresh-like characteristics to be used in the preparation of fruit salads or as a food ingredient. In addition, this study evaluates the influence of syrup concentration during osmotic dehydration as well as initial firmness of the mangoes on physicochemical, mechanical and optical properties during storage.

Materials and Methods

Sample preparation

Mango (*Mangifera indica L*. var. Tommy Attkins) fruits in different ripening stages were purchased in a local market. The mangoes were manually washed with tap water, and classified based on three different ripening stages: > 5 (firm), 3-4.9 kg (medium), and 0.2-2.9 kg (soft). This classification was made through a puncture test with a penetrometer (Fruit pressure tester mod. FT 327, 3-27 lbs, Instituto per la valorizzazione dei prodotti agricoli, Italy). Each fruit was skinned prior to penetration. The fruit was held firmly, and the plunger was then placed against the fruit while pressing with increasing strength until the plunger tip penetrated into the fruit tissue. This step was performed twice on each mango. Two large pieces parallel to the stone were cut from each fruit with a food processing machine (model 808. Berkel Incorpotated. Laporte, Indiana, USA). Slices (1.5 cm thick) were cut and subjected to osmotic and freezing treatments. A separate batch from each initial ripening stage level without treatment was vacuum packaged, frozen and stored as a control treatment

Osmotic treatments

All the treatments were performed at room temperature. Osmotic solutions of 10^{o}, 20^{o}, and 30^{o}Brix were prepared with commercial sucrose. The following reagents were added to the syrups: ascorbic acid (Sigma-Aldrich, St. Louis, MO, USA) (0.1%) as antioxidant [15], calcium chloride (Sigma-Aldrich, St. Louis, MO, USA) (0.25%) to improve texture [15], citric acid (J.T. Baker, Phillipsburg, NJ, USA) (0.5%) to lower the pH and avoid microbial spoilage [15], and sodium metabisulfite (Sigma-Aldrich, St. Louis, MO, USA) (500 ppm) to avoid microbial spoilage[15]. The slices were immersed into the solution in a 1:25 (w/w) ratio, which was large enough to avoid significant changes in the concentration throughout the process [16]. The weight

of the slices per batch was 2.75 kilograms of fruit and the room temperature was 20°C. Processing time was four hours for all treatments. This time was chosen on the basis of previous studies [17]. When the osmotic treatments were completed, the slices were drained and rinsed with cold tap water, then dried with paper towels before being placed into multilayer plastic films (CRYOVAC, Duncan, SC, USA). Air from the bags was removed, and the samples were sealed in a vacuum packaging sealer (600, Henkelmann, Netherlands). The fruits were then frozen, and stored at -18 °C for 20 weeks.

Analytical determinations

Moisture content was determined in duplicate by drying to a constant weight at 60°C (AOAC 20.013)[18]. The method for preparation of the fruit samples (AOAC 920.149) [18] was used prior to analysis of pH, soluble solids concentration, and titratable acidity. Soluble solids were analyzed by measuring the refractive index of the prepared fruit juice samples with a refractometer (Bausch and Lomb, USA) at 23°C as room temperature (AOAC 932.14) [18]. AOAC method number 942.15 [18] was used to determine titratable acidity at room temperature. Official method 981.12 [18] was used to measure the pH of the fruit juice prepared from the mango samples. Water activity was determined using dew point equipment (Aqua Lab, Decagon model series 3, Pullman, Washington, USA) at room temperature. Ascorbic acid (vitamin C) was measured through 2,6-Dichlorondophenol titrimetric method 967.21 [18].

Optical and mechanical properties

The optical properties of the samples were measured through the surface reflectance spectra in a spectrocolorimeter (Minolta CM 1000R, Japan). Lightness (L^*), hue (h^*) and chroma (C^*) were calculated from the average of six color measurements.

The mechanical properties of fresh and frozen-thawed samples were analyzed through a two-bite compression test, which was conducted using a TA.XT2i texture analyzer (Stable Micro Systems, England), and a 25 kg (± 1g) load cell was used to conduct Texture Profile Analysis (TPA). For each treatment, eight cubic replicates of 1 cm^3 were performed for each treatment. The resulting two peak curve was then analyzed by TPA macro files to obtain the height of first peak (hardness), the negative area between the two peaks (adhesiveness), the ratio of the two peak areas (cohesiveness),and the distance from the start of the second peak to the highest point of the second peak (springiness). Gumminess was the product of hardness and cohesiveness, and chewiness was the product of gumminess and springiness.

Experimental design and statistical analysis

The experimental design constituted a complete factorial design. Four concentrations of sugar (0^o, 10^o, 20^o and 30^oBrix) and three different texture levels (firm, medium, and soft) were evaluated four times (immediately after treatment, week 7, week 12, and week 20) during 20 weeks of storage. In each treatment, the sample was characterized as to moisture content, soluble solids, water activity, pH, color, titratable acidity, and texture.

Analysis of variance was performed using SAS software (SAS Institute Inc., 2000), and the Student-Newman-Keul's multiple range test was used to compare differences among mean values. Mean values and pooled Standard Errors of the Mean (SEM) were reported, and the significance was defined at $P \leq 0.05$.

Results and Discussion

Chemical characteristics

Titratable acidity and pH

Acidity values (g citric acid/100 g pulp) of mango slices treated in different osmotic solutions stored at -18 ± 2°C are presented in Table 3.2. The ANOVA analysis showed that there was a significant decrease in acidity during storage and among the different ripening stages of the fruit. Initially, osmotically dehydrated (10-30°Brix) slices of medium and soft mango, showed lower acidity than 0°Brix slices before freezing. This may be attributed to minimal losses of acids due to the osmotic treatment. After frozen storage, the appearance of smaller titratable acidity values of 10 and 20°Brix pieces, suggests that the organic acid metabolism changed due to the osmotic treatment and the freezing process. These results are in agreement with those reported for Tovar [19] and Goratti Netto [20]. Slices treated in 30°Brix syrups in hard and soft ripening stages did not show significant changes in the acidity values. On the other hand, for slices from medium and soft mangoes treated in 10°Brix solutions, less retention of acidity was found.

Control (0°Brix) slices showed the highest pH values for hard, medium and soft mangos during storage (Table 3.1). Corresponding to changes in acidity, pH values displayed significant changes with differences in the initial firmness of the fruit, storage time, and the amount of sucrose of the syrup. Slices treated in various syrups before freezing reported lower pH values probably due to the addition of acidulants (citric acid) to the syrup in order to avoid microbial spoilage of the samples during storage. These pH values are able to control microbial growth [19]. The variations found in pH values could also be explained by the presence of a biochemical pH-stat [21]. This theory states that acidification of the cytoplasm of the cells should occur under

environmental stress. Biochemical pH-stat would be assumed as a security mechanism for the 'proton system', so that it could cope with the potential acidification of the cytoplasm under stress conditions [21]. The change of pH during storage could be explained because after freezing, many solutes may be supersaturated in the unfrozen phase. In time this may crystallize or precipitate which changes the relative amounts of solutes and their initial concentrations. Therefore, the ionic strength can change and also pH due to changing ratios of buffer components [22, 23].

Total soluble solids, water activity, and moisture content

A significant increase over time was observed in soluble solids content of hard, medium, and soft slices. In addition, the syrup concentration (10^o, 20^o and 30^oBrix) in which the mangoes were immersed had a significant impact on total soluble solids composition of the mango slices after freezing and storage (Table 3.2). For hard mangoes, there was a significant sugar uptake by the mango slices, which increased as the syrup increased in sucrose concentration. Medium mango had significant changes over time for 30^oBrix slices and for 0^oBrix slices. Soft mango slices showed the highest soluble solids content. This could be explained because free sugars, including glucose, fructose, and sucrose, generally increase during ripening; however, the sucrose content increases three- to four-fold [24].

Although the 0^oBrix slices showed significant differences at all firmness levels, they did not develop soluble solids to the same level as the 10-30^oBrix slices. Osmotic treatment may be a cause of the greater solids uptake of the treated slices. This increase could be attributed to the generation of soluble solids from reserve starch [25, 26] as well as the reduction of the particle size of the fruit to a certain level, above which solid gain is highly favored [27, 28]. Also, pretreatment with chemicals (SO_2), blanching, or freezing favors the solid gain as compared to

water loss because impregnation phenomena is enhanced, in that permeability increases and selectivity decreases [27-30]. Mass transfer has been reported to occur mainly during the first two hours, after which the mass transfer rates become progressively lower until water loss diminishes, whereas solute gain continues to increase steadily [31, 32]. The observed effects in mango tissue may be explained through the great influence of solution viscosity on the solution uptake by hydrodynamic mechanisms of the tissue pores. This gain greatly contributes to solute uptake [33].

Moisture content of slices significantly decreased as the sucrose concentration of the solutions increased (Table 3.3). High concentration solutions reported decreased amounts of water in hard, medium and soft mango slices than for mango slices treated in low concentration solutions. Tedjo and coworkers [5], showed that the moisture content of mango during osmotic treatment decreased with osmotic dehydration. The increased water loss from mango slices treated in 30^{o}Brix solutions could be explained because mass exchanges are favored by using high concentration solutions [30, 34-38]. The water activity values (a_w) did not show significant differences between syrup concentrations where slices were immersed (Table 3.3). Statistical analysis demonstrates that there was no significant difference based on initial firmness of the fruit and after storage. Hard and medium mango slices presented significantly higher a_w values than soft mango slices. For soft mango, there was no significant difference; however, water activity of these slices tended to decrease slightly overtime.

Vitamin C content

The results illustrated in Table 3.1 revealed a significant decrease in the vitamin C values of slices depending upon sucrose solution (0^{o}-30^{o}Brix), initial firmness (hard, medium and soft) and storage period (0, 7, 12 and 20 weeks). During week 0, the amount of vitamin C was

significantly higher in control (0°Brix) slices than in 10-30°Brix slices from all ripening stages. Therefore, osmotic dehydration had a substantial effect on the decrease of vitamin C content which agrees with results obtained by Forni [39]. Vitamin C values for hard mango were generally higher than values for medium and soft mango slices. These results could be explained because vitamin C content decreases as ripening progressed in mango fruit, as previously reported [19, 35]. There were no significant differences over time for 30°Brix treatments in hard, medium and soft slices. This means that osmotic dehydration was able to prevent vitamin C losses, which has an important antioxidant role in the tissues [36]. Control (0°Brix) slices, 10° and 20°Brix slices significantly decreased the vitamin C content during freezing storage.

Vitamin C stability in foods depends on several factors, such as low pH, oxygen availability, and catalysts, among others. In addition, it is possible that this vitamin could be degraded by light [40] and enzymatic activity [41], to which sliced tissues were exposed [19]. Although the mango slices remained vacuum packaged during storage, the presence of sucrose at low pH (3-4) could have increased the rate of anaerobic degradation, as explained by Gregory [37, 38]. Also, during the process of freezing, storage, and thawing, vitamins and minerals may dissolve in liquid exuding from the fruits [42]. Drip losses from thawing indicate that water soluble compounds leach out from the cell tissues, and could be another cause for poor vitamin C retention in those samples.

Color changes

The application of the osmotic dehydration process, as well as storage time, provoked significant changes on the fruit surface. Table 3.4 shows the color differences of mango slices in different syrup concentrations during storage at -18°C for 20 weeks. Lightness (L^*), hue angle (h^*), and chroma (C^*) values were obtained for fresh and processed fruit. Homogeneous values

of each color coordinate according to the student-Newman-Kewl's test were reflected by the same letter superscript. After freezing-thawing, L^*, C^* and h^*, values, demonstrated significant differences between treatments during storage of the hard, medium and soft mango slices.

Lightness (L^*) values for most control and 10°, 20°, and 30°Brix slices significantly decreased over time (Table 3.4). This may be due to osmotic treatmens, frozen storage and thawing which implies fruit browning mainly because of cellular breakdown and enzyme activity [6]. Related to the osmotic treatments, L^* decreased significantly depending on the sucrose concentration, thus 30°Brix slices were darker than 10°Brix slices. This behavior can be explained due to outflow of cellular liquid to intracellular spaces, along with the subsequent transparency gain associated with the cell compartmentation loss during freezing [6]. The differences for 10°, 20° and 30°Brix slices were less marked over time than for the 0°Brix slices. Additionally, hard slices from 20° and 30°Brix and medium slices from 20°Brix showed a better performance than the rest of the slices over time. These results indicate that the addition of reducing agents (ascorbic and citric acids in this case), as well as the sucrose content could have partially prevented browning. Mukerjee and coworkers [43] reported that addition of 0.3% of citric acid to mango pulp suppressed browning during frozen storage.

Chroma (C^*) was the color attribute subjected to the greatest changes. Both osmotic dehydration and freezing storage provoked loss of color chroma, especially for 0°Brix slices (Table 3.4). This could be due to the small contribution of carotenoid degradation occurring during frozen storage. Decreases in β-carotene content of mango slices has been studied [44] during frozen storage at -18°C. As β-carotene is fat-soluble, it is not likely to be subject to leaching losses, but reaction like cis-trans isomerization or epoxidation during food processing and storage, as well as any oxidative changes may decrease pigment levels [42]. Chroma values

from 20°Brix on hard mango and 10°-30°Brix slices in medium mango did not report significant changes at $P \leq 0.05$ over time. Changes in sample transparency have a great impact on color, as selective absorption of the solution occurs to different degrees, causing changes in lightness and chroma. The greater the sample transparency gain, the darker the sample and the less vivid the color of the fruit [10].

The hue angle value (h^*) had significant changes both, over time and depending on the sucrose composition of the slices. In general, hard and medium mango slices reported hue angle values higher than 90° meaning a more green-yellow color [42]. Soft mango slices reported more hue angle values below 90°, meaning a less green character [42]. This could be due to the carotenoid content of mango fruit, which gives the yellow-orange color to the fruit and tends to increase as fruit ripens [42]. It can be seen (Table 3.4) that during frozen storage there is a reduction on the hue angle values.

Textural analysis

A multi-factorial ANOVA showed that all factors (initial firmness, sucrose concentration and freezing storage) influenced the degree of fruit hardness values (Table 3.5). Initially, there was a significant decrease on hardness based on the initial ripening stage for all treatments. Mango softening is presumably related to the depolymerization and solubilization of pectic substances in the middle lamella of the cell wall, and is believed to involve cell wall hydrolases [46, 47]. Pectinmethylesterase (PME) activity decreases in mangoes during ripening. PME catalyzes the hydrolysis of methyl ester along the pectin chain to produce free carboxyl groups, which bind with cations such as calcium to form salt bridges between adjacent pectin molecules [47]. Also, significant differences were present depending on the sucrose content of the slices,

thus hardness values were significantly lower for treated slices than those of 0°Brix mango slices in all ripening stages. Similar results have been reported for mangoes [5].

Mango slices from 10°Brix for medium and soft slices and 30°Brix for hard slices reported no significant changes in hardness values over time. On those slices, removal of water and infusion of sucrose and other reagents were sufficient to reduce freezing damage on the tissues. Frozen storage caused significant changes on hardness values on the rest of the treatments. Mechanical damage from ice crystals formed during frozen storage could be the cause of the decrease on hardness values over time. On those samples, ice crystals were formed and continued to grow in size during storage which stressed the fragile cellular structures of mango tissue causing irreversible damage [22, 23].

Cohesiveness, which is a measure of the strength of the internal bonds of the food material of the food [48], was significantly higher for 0°Brix mango slices than for 10-30°Brix for hard, medium, and soft slices. This indicates that more energy was required to separate pieces of the untreated slices than for treated ones after freezing-thawing. Storage time had a significant effect on 0°Brix mango slices from hard, medium and soft slices, while it did not have a significant effect for treated slices (Table 3.5). This suggests that treatments helped to maintain cohesiveness during storage. Springiness, a measure of the recovery in height after a sample has been compressed by the teeth during mastication [48], showed significant effects over storage time, sucrose concentration of the solutions where slices where immersed, and the interaction of both. The storage time had a significant effect on 0°Brix slices from hard, medium and soft slices (Table 3.5). Although 0°Brix slices changed over time, initial values of springiness were significantly higher than values for treated slices, especially for soft mango. Slices immersed in

syrup solutions (except for 20°Brix in hard and medium and 30°Brix for medium) did not demonstrate significant effects during storage.

Adhesiveness is defined as the negative force area after the first bite, represented by the work necessary to pull a compressing plunger away from the sample [49]. In all slices, there was a significant effect noted for initial ripening stage and its interaction with sucrose content in all slices (Table 3.6). Samples with the highest adhesiveness values came from soft slices treated in syrups of 20-30°Brix. In other studies, Banjongsinsiri [47] reported that mango treated with calcium chloride was more adhesive and sticky than untreated mangoes.

The analysis of variance (ANOVA) for gumminess, which is a measure of the force necessary to disintegrate particles for swallowing [48], showed a significant effect upon the slices of sucrose solution (0-30°Brix), initial ripening stage (hard, medium and soft) and along storage period (0, 7, 12 and 20 weeks) (Table 3.6). Gumminess decreased significantly among initial ripening degree; thus, hard slices had higher gumminess values than soft slices. In addition, initial values of gumminess for 0°Brix slices were significantly higher than values for treated slices; after seven weeks of storage, gumminess values dramatically decreased, and kept changing over time. Although the effect of sucrose solution was significantly different for all slices, there is not a specific treatment that shows that more or less sucrose helped to preserve more gumminess in slices. Storage time had no significant effect on 30°Brix slices from hard mangoes, 10°-30°Brix slices from medium mangoes, and 10°Brix slices from soft mango. Chewiness, the energy for masticating the food product until it is ready for swallowing [48]. Significant differences were found for sucrose level, initial ripening stage and storage time (Table 3.6).

There was a high decrease of chewiness in 0°Brix samples as compared to treated samples over time in all initial ripening stages. Chewiness values were lower for initially softer mango slices, which further supports the previously discussed observations for hardness and gumminess. Factors such as variety, maturity, growing area, and seasonal variations influence frozen storage of fruits to an extent that may override the positive effect of freezing [42]

Mechanical properties of fruits change, not only during maturation, ripening and storage, but also during processing due to alteration of structural components [50]. The major changes induced by osmotic treatments, which affect the mechanical behavior of plant tissues, are loss of cell turgor (important in crispness and succulence of fruits), alteration of middle lamella, alteration of cell wall resistance, establishment of water and solute concentration profiles, changes in air and liquid volume fractions in the sample, and changes in sample size and shape [51]. In addition, frozen storage and thawing often produce changes in fruit texture [42].

Conclusions

The effects of osmotic syrup concentration and initial ripening stage of mangoes upon physicochemical, mechanical and optical properties during frozen storage was evaluated. Osmotic treatments and freezing storage significantly reduced all physicochemical, color and TPA parameters when compared to fresh mango from all ripening stages. Negative effects of osmotic treatments and freezing such as decreased vitamin C retention, darker and less vivid color, as well as a strong increase in product translucency, drip loss, and mechanical damage were observed. However, the presence of sugars and preservatives provided more protection during freezing and storage of treated slices than untreated ones over storage time.

Treatments carried out with the highest osmotic concentration (30^{o}Brix) showed the best preserved textural properties (except for adhesiveness and chewiness) after freezing-thawing, probably because of a greater evenness of water distribution is reached in the tissue. This type of treatment also had a greater influence on solids gained than did treatments with less osmotic concentration, as well as smaller alterations in organic acids and improved retention in vitamin C content.

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Table 3.1
Effect of initial Firmness and sucrose level on pH and total soluble solids (TSS) (g/100 g pulp) in mango slices stored at -18±2°C[ab]

Treatment	Initial Firmness	Sucrose Level	Storage Period (weeks)				S.E.M.[c]
			0	7	12	20	
pH	Hard	0	3.65Aa	3.53Ba	3.11Ca	3.05Ca	0.015
		10	3.03Ab	2.81Bb	2.72Bb	2.91Cb	0.009
		20	3.05Ab	2.91ABb	2.79ABb	2.55Bb	0.025
		30	3.07Ab	2.79Bb	2.63Cb	2.45Db	0.0008
	S.E.M.		0.005	0.013	0.021	0.007	
	Medium	0	3.42Aa	3.18Ba	2.97Ca	2.97Ca	0.001
		10	3.1Aa	2.57Bc	2.46Bb	2.35Bb	0.005
		20	2.9Ab	2.59Bc	2.57Bb	2.46Bb	0.004
		30	3.2Aa	2.93Bb	2.6Cb	2.53Bb	0.082
	S.E.M.[d]		0.003	0.0006	2.667	0.0002	
	Soft	0	3.63Aa	3.18Aab	3.01Ca	2.93Ca	0.0009
		10	3.63Aa	2.8Bb	2.49Cb	2.35Cb	0.005
		20	2.86Ac	2.9Ab	2.80Ab	2.46Bb	0.0045
		30	3.26Ab	3.33Aa	2.42Bb	2.53Bb	0.082
	S.E.M.		0.002	0.082	0.006	0.0002	
TSS	Hard	0	6.60Bd	6.75Bc	11.40Ab	10.57Ac	0.906
		10	9.17Cc	11.86Ab	10.35Ab	10.64Ac	0.738
		20	12.34Ab	11.77Ab	12.99Ab	13.00Ab	0.462
		30	18.53Ca	17.9Ca	21.82Ba	23.23Aa	1.342
	S.E.M.		1.366	1.577	0.506	0.017	
	Medium	0	13.46Bb	14.68Bb	13.92Bb	15.89Ab	0.516
		10	11.42Ab	11.84Ab	13.03Ab	13.53Ab	1.006
		20	16.78Aa	19.40Aa	17.84Aa	18.60Aa	6.947
		30	16.09Da	19.43Ca	22.13Ba	24.69Aa	0.703
	S.E.M.		1.713	5.554	1.440	0.465	
	Soft	0	17.41Ab	16.65Ac	16.65Ac	20.43Ac	2.561
		10	17.93Bb	19.43Bb	22.00Ab	22.15Ab	1.514
		20	19.80Cb	23.01Bb	26.12Ab	27.17Aa	0.611
		30	24.54Ba	25.42Ba	27.24Ba	27.83Aa	0.3552
	S.E.M.		1.923	1.007	1.893	0.218	

[a] Means in the same row followed by the same letter (A-D) are not significant ($p<0.05$)
[b] Means in the same column followed by the same letter (a-d) are not significant ($p<0.05$)
[c] S.E.M., Standard errors of the mean (n=8).
[d] S.E.M., Standard errors of the mean (n=4)

Table 3.2
Effect of initial Firmness and sucrose level on Vitamin C content (mg ascorbic acid/100g pulp) and acidity (g citric acid/100 g pulp) in mango slices stored at -18±2°C[ab]

Treatment	Initial Firmness	Sucrose Level	Storage Period (weeks)				S.E.M.[c]
			0	7	12	20	
Vitamin C	Hard	0	42.17Aa	19.97Ba	11.24Ca	3.05Dc	18.33
		10	25.00Ab	12.61Bb	15.80Ba	12.48Ba	15.25
		20	17.14Ab	9.75Bb	9.48Bb	8.81Bb	4.85
		30	16.42Ab	13.95Ab	12.04Aa	10.79Ab	17.11
	S.E.M.		25.51	8.97	19.40	4.51	
	Medium	0	24.76Aa	9.68Bc	7.27Bc	3.50Bc	11.38
		10	13.80Ab	14.51Ab	14.76Ab	6.91Bc	5.72
		20	21.12Aa	13.75Bb	10.91Bab	10.74Bb	10.86
		30	20.62Aa	18.42Aa	17.91Aa	18.47Aa	6.55
	S.E.M.[d]		24.41	2.02	5.02	9.80	
	Soft	0	12.14Aa	6.65ABb	3.30Bc	1.88Bc	10.54
		10	11.90Aa	13.28Aa	13.34Aa	12.64Aa	3.46
		20	10.24Aa	6.64Bb	8.24Bab	6.31Bb	1.44
		30	5.49Ab	6.68Ab	7.03Ab	5.68Aa	1.58
	S.E.M.		2.15	9.76	3.62	1.49	
Acidity	Hard	0	0.697Aa	0.30Bb	0.38Ba	0.28Ba	0.009
		10	0.632Aa	0.42Ba	0.34Ca	0.31Ca	0.004
		20	0.624Aa	0.52Ba	0.34Ca	0.33Ca	0.002
		30	0.378Ab	0.42Aa	0.34Aa	0.37Aa	0.008
	S.E.M.		0.01	0.00001	0.008	0.001	
	Medium	0	0.52Aa	0.49Aa	0.42Aa	0.34Bb	0.009
		10	0.39Ab	0.26Bb	0.28Bb	0.31Bb	0.003
		20	0.25Ab	0.35Ab	0.31Ab	0.33Ab	0.0006
		30	0.48Aa	0.37Bb	0.38Bab	0.45Ba	0.0007
	S.E.M.		0.001	0.0007b	0.001	0.0001	
	Soft	0	0.41Aa	0.27Bb	0.30ABa	0.20Bb	0.002
		10	0.49Aa	0.27Bb	0.31Ba	0.21Cb	0.0005
		20	0.48Ba	0.42Aa	0.22Ca	0.29Ba	0.003
		30	0.35Ab	0.43Aa	0.29Aa	0.31Aa	0.005
	S.E.M.		0.0009	0.0008	0.001	0.006	

[a] Means in the same row followed by the same letter (A-D) are not significant ($p<0.05$)
[b] Means in the same column followed by the same letter (a-d) are not significant ($p<0.05$)
[c] S.E.M., Standard errors of the mean (n=8).
[d] S.E.M., Standard errors of the mean (n=4)

Table 3.3
Effect of initial firmness and sucrose level on water activity (a_w)and moisture content (g/100 pulp) in mango slices stored at -18±2°C[ab]

Treatment	Initial Firmness	Sucrose Level	Storage Period (weeks) 0	7	12	20	S.E.M.[c]
a_w	Hard	0	0.986Aa	0.986Aa	0.982Aa	0.981Aa	0.0025
		10	0.989Aa	0.987Aa	0.986Aa	0.988Aa	0.00003
		20	0.985Aa	0.987Aa	0.983Aa	0.982Aa	0.00007
		30	0.975Ab	0.973Ab	0.977Aa	0.971Aa	0.00007
	S.E.M.		3.3E-5	5E-5	0.002	0.0001	
	Medium	0	0.988Aa	0.987Aa	0.982Aa	0.985Aa	4.7E-5
		10	0.964Aa	0.982Aa	0.985Aa	0.979Aa	3.4E-5
		20	0.980Aa	0.979Aa	0.980Aa	0.979Aa	3.8E-5
		30	0.979Aa	0.977Ab	0.978Ab	0.970Ab	2.2E-5
	S.E.M.[d]		3.1E-5	1.1E-5	2.9E-5	1.3E-5	
	Soft	0	0.982Aa	0.989Aa	0.982Aa	0.985Aa	2.6E-5
		10	0.989Aa	0.989Aa	0.980Aa	0.972Aa	8.4E-5
		20	0.980Aa	0.982	0.978Aa	0.972Aa	5.5E-5
		30	0.973Ab	0.973Aa	0.971Aa	0.969Ab	5.9E-5
	S.E.M.		3.4E-5	3.9E-5	7.7E-5	7.3E-5	
Moisture Content	Hard	0	0.870Aa	0.876Aa	0.878Aa	0.876Aa	0.000004
		10	0.837Ab	0.839Ab	0.838Ab	0.828Ab	0.0006
		20	0.821Cb	0.813Ab	0.819Ab	0.817Ab	0.00003
		30	0.793Ac	0.794Ac	0.788Ac	0.785Ac	0.00002
	S.E.M.		0.0003	0.00002	0.00001	0.00003	
	Medium	0	0.873Aa	0866Aa	0.861Aa	0.868Aa	0.0004
		10	0.836Ab	0.844Ab	0.832Ab	0.840Ab	0.00009
		20	0.825Ab	0.829Ac	0.817Ab	0.815Ac	0.00007
		30	0.786Ac	0.788Ad	0.788Ab	0.787Ad	4.22E-6
	S.E.M.		7.8E-5	3.4E-4	0.0012	4.2E-6	
	Soft	0	0.839Aa	0.831Aa	0.835Aa	0.833Aa	6.6E-5
		10	0.820Ab	0.827Aa	0.824Aa	0.823Aa	2.2E-5
		20	0.820Ab	0.824Aa	0.812Aa	0.815Ab	1.4E-4
		30	0.747Ac	0.749Ab	0.745Ab	0.748Ac	7.7E-5
	S.E.M.		1.6E-5	5.9E-5	4.3E-5	1.8E-5	

[a] Means in the same row followed by the same letter (A-D) are not significant ($p<0.05$)
[b] Means in the same column followed by the same letter (a-d) are not significant ($p<0.05$)
[c] S.E.M., Standard errors of the mean (n=8).
[d] S.E.M., Standard errors of the mean (n=4)

Table 3.4
Effect of initial firmness and sucrose level on lightness (L^*), chroma (C^*) and hue angle (h^*)in mango slices stored at -18±2°C[ab]

Treatment	Initial Firmness	Sucrose Level	Storage Period (weeks) 0	7	12	20	S.E.M.[c]
L^*	Hard	0	57.09Aa	49.16Ba	49.71Bb	43.97Cc	7.618
		10	51.69Ab	49.93ABa	48.70Bb	47.49Bb	2.326
		20	51.24Ab	51.19Aa	51.04Aa	52.14Aa	4.815
		30	47.20Ac	46.59Ab	48.44Ab	48.82Ab	7.609
	S.E.M.		0.005	0.01	0.021	0.006	
	Medium	0	55.70Aa	50.78Ba	52.90Ba	52.01Ba	10.924
		10	49.91Ab	50.65Aa	50.53Aa	51.09Aa	7.795
		20	47.77Ab	49.26Aa	47.56Ab	50.64Aa	11.37
		30	47.0Ab	48.6Aa	49.14Ab	45.16Bb	2.817
	S.E.M.[d]		0.003	6.2E-4	2.667	0.001	
	Soft	0	55.90Aa	49.92Bb	52.43Ba	53.43Ba	10.014
		10	55.21Aa	52.58Ba	53.71ABa	49.35Cb	0.747
		20	56.74Aa	51.11Bab	52.01Ba	49.48Bb	6.814
		30	55.88Ab	52.18Ba	49.75Bb	48.39Bb	6.086
	S.E.M.		0.002	0.082	0.006	7.1E-4	
C^*	Hard	0	33.52Aa	26.69Ba	20.19Cb	22.0Ca	6.476
		10	27.78Ab	27.84Aa	22.5Ba	18.65Bb	11.023
		20	27.01Ab	25.42Aa	27.21Aa	24.88Aa	13.179
		30	24.35Ac	24.88Aa	16.29Bc	12.22Bb	13.565
	S.E.M.		8.06	7.807	14.307	16.214	
	Medium	0	39.00Aa	31.06Ba	26.02Bab	20.96Cb	17.592
		10	24.10Ab	27.74Aa	29.25Aa	26.82Aa	14.748
		20	21.39Ab	26.08Ab	22.27Abc	23.29Aa	25.807
		30	22.69Ab	23.55Ab	19.53Ac	20.10Ab	8.351
	S.E.M.		16.11	7.231	10.443	32.715	
	Soft	0	34.09Ab	35.18Aa	30.16Aa	30.26Aa	21.606
		10	36.39Aab	35.06Aa	33.64Ba	30.73Bab	2.774
		20	39.48Aa	29.47Bb	31.11Ba	27.30Bb	13.797
		30	32.76Ab	31.85Aa	25.05Bb	25.90Bb	12.308
	S.E.M		11.26	15.02	9.931	14.276	
h^*	Hard	0	102.11Aa	100.05Ab	98.08Bb	97.71Bb	3.294
		10	100.58Aa	102.95Aa	103.70Aa	95.88Bb	8.894
		20	99.65Ab	100.81Ab	99.0Aab	96.23Bb	6.031
		30	101.21ABa	103.55Aa	99.81Bab	100.78Ba	5.299
	S.E.M.		7.285	4.885	6.978	4.369	
	Medium	0	100.26Aa	97.25Ba	93.3Cb	94.51Cb	1.711
		10	96.95Aab	94.183Ab	95.18Aa	94.7Ab	3.118
		20	98.91Aa	93.61Ab	95.85Aa	94.95Ab	11.661
		30	95.46Ab	96.53Aa	96.7Aa	97.43Aa	1.924
	S.E.M.		3.494	9.454	1.286	4.179	
	Soft	0	91.93Aab	90.73Ab	89.90Ab	92.11Aa	3.813
		10	88.56Ab	89.13Ab	89.45Ab	89.21Ab	1.536
		20	93.46Aa	90.08Bb	90.91Ba	89.11Bb	3.470
		30	92.86Aa	95.06Aa	92.58Aa	88.28Bb	9.319
	S.E.M.		3.227	6.712	4.134	4.066	

[a] Means in the same row followed by the same letter (A-D) are not significant ($p<0.05$)
[b] Means in the same column followed by the same letter (a-d) are not significant ($p<0.05$)
[c] S.E.M., Standard errors of the mean (n=8).
[d] S.E.M., Standard errors of the mean (n=4)

Table 3.5
Effect of initial firmness and sucrose level on hardness cohesiveness and springiness in mango slices stored at -18±2°C[ab]

Treatment	Initial Firmness	Sucrose Level	Storage Period (weeks) 0	7	12	20	S.E.M.[c]
Hardness	Hard	0	9473.3Aa	4622.0Ba	5089.0Ba	5954Ba	52.018
		10	4194.7Ab	4174.0Aa	2877.9Bb	2453.9Bb	15.415
		20	6274.0Ab	43.99.3Ba	3304.3Bab	2656.8Bb	26.774
		30	4247.0Ab	3556.2Aa	4215.7Aa	3544.7Aab	30.366
	S.E.M.		33.907	43.751	26.774	26.774	
	Medium	0	5857.2Aa	4065.0Ba	1649.9Cb	1896.5Ca	27.794
		10	2417.3Ab	2380.2Ab	1950.6Bb	1792.5Ba	48.683
		20	3448.6Ab	2610.7ABb	2605.9ABa	1876Ba	54.800
		30	2002.8Ab	2687.8Ab	1928.4Bb	721.Cb	86.233
	S.E.M.[d]		16.706	74.143	15.299	58.756	
	Soft	0	1215.9Ab	967.9ABab	836.2ABa	498.3Bb	19.857
		10	652.5Ac	641.6Ab	640.2Ab	445.0Ab	55.345
		20	1629.9Ab	909.8Bab	488.9Cc	276.10Cc	83.634
		30	1125.6Aa	1109.3Aa	839.4Ba	617.2Ba	26.511
	S.E.M.		28.801	12.187	87.090	10.568	
Cohesiveness	Hard	0	0.311Aa	0.112Bb	0.126Ba	0.123Ba	62.E-4
		10	0.138Ab	0.143Aa	0.112Bab	0.113Ba	1.8E-4
		20	0.137Ab	0.138Aa	0.121Aab	0.127Aa	5.4E-4
		30	0.112Ac	0.116Ab	0.106Ab	0.102Aa	4E-4
	S.E.M.		5.8E-4	1.6E-4	1.8E-4	8.2E-4	
	Medium	0	0.233Aa	0.102Bb	0.112Ba	0.095Ba	1.2E-4
		10	0.137Ab	0.112Aa	0.111Aab	0.125Aa	7.1E-4
		20	0.118Ab	0.119Aa	0.108Aab	0.091Aa	4.2E-4
		30	0.101Ab	0.102Ab	0.093Ab	0.125Aa	0.001
	S.E.M.		1.3E-3	0.003	3.9E-4	0.015	
	Soft	0	0.233Aa	0.106Bab	0.145ABa	0.145ABa	5.9E-4
		10	0.131Abc	0.168Aa	0.128Aa	0.154Aa	2.2E-4
		20	0.157Ab	0.180Aa	0.140Aa	0.130Aa	1.2E-4
		30	0.108Ac	0.117Aab	0.106Aa	0.12Aa	3E-5
	S.E.M		0.001	2.7E-4	3.4E-4	2.4E-4	
Springiness	Hard	0	0.608Aa	0.382Ba	0.338Bb	0.370Ba	0.003
		10	0.306Ab	0.344Aa	0.322Ab	0.352Aa	0.005
		20	0.464Ab	0.318Ba	0.397Ba	0.221Cb	0.010
		30	0.297Ab	0.335Aa	0.318Ab	0.305Aa	0.008
	S.E.M.		3.6E-4	6.9E-4	2.5E-4	0.014	
	Medium	0	0.656Aa	0.351Ba	0.308Ba	0.246Ca	0.005
		10	0.267Ab	0.244Ab	0.267Ab	0.268Aa	0.001
		20	0.32Ab	0.295Bab	0.252Ba	0.265Ba	0.002
		30	0.377Ab	0.258Bb	0.258Bb	0.253Ba	0.004
	S.E.M.		2.5E-4	0.003	0.003	0.005	
	Soft	0	0.957Aa	0.295Ba	0.337Ba	0.340Ba	0.040
		10	0.337Ab	0.201Aa	0.271Ab	0.272Ab	0.020
		20	0.275Ab	0.247Ab	0.247Ab	0.225Ab	0.010
		30	0.225Ab	0.217Aa	0.271Ab	0.231Ab	0.005
	S.E.M.		0.023	0.015	0.016	0.005	

[a] Means in the same row followed by the same letter (A-D) are not significant ($p<0.05$)
[b] Means in the same column followed by the same letter (a-d) are not significant ($p<0.05$)
[c] S.E.M., Standard errors of the mean (n=8).
[d] S.E.M., Standard errors of the mean (n=4)

Table 3.6
Effect of initial firmness and sucrose level on adhesiveness gumminess and chewiness of mango slices stored at -18±2°C[ab]

Treatment	Initial Firmness	Sucrose Level	Storage Period (weeks) 0	7	12	20	S.E.M.[c]
Adhesiveness	Hard	0	-31.37Aa	-22.44Aa	-21.23Aa	-15.90Aa	16.56
		10	-11.99Ab	-11.01Ab	-11.63Ab	-13.93Ab	67.16
		20	-23.64Aab	-19.04Aa	-17.15Aa	-16.83Aa	46.35
		30	-18.88Aab	-14.28Ab	-16.65Aab	-20.17Aa	11.92
	S.E.M.		18.367	72.306	80.77	61.73	
	Medium	0	-23.75Aa	-20.02Aa	-11.31Ab	-19.28Aa	87.05
		10	-17.02Aab	-20.55Aa	-21.94Aa	-23.67Aa	49.31
		20	-14.02Ab	-16.90Ab	-19.90Aab	-15.77Ab	63.60
		30	-20.67Aa	-24.79Aa	-26.83Aa	-25.52Aa	20.08
	S.E.M.[d]		91.96	61.82	84.22	16.90	
	Soft	0	-25.29Aa	-29.37Aa	-29.27Aa	-28.69Aa	95.18
		10	-23.79Ab	-23.37Aa	-22.71Aa	-20.98Ab	15.85
		20	-29.85Aa	-30.37Aa	-28.14Aa	-24.90Aa	20.19
		30	-29.66Aa	-29.05Aa	-29.63Aa	-29.15Aa	19.94
	S.E.M.		18.98	14.86	19.01	12.65	
Gumminess	Hard	0	3018.9Aa	720.0Ba	613.54Ba	758.3Ba	5.12
		10	693.7Ab	472.1Aa	302.79Bb	327.6Bb	5.31
		20	858.9Ab	362.9Bb	491.81Bab	331.2Bb	6.70
		30	488.2Ab	438.5Ab	453.69Aab	451.2Ab	7.37
	S.E.M.		4.688	1.348	3.60	5.293	
	Medium	0	1777.3Aa	412.57Ba	509.95Ba	472.94Ba	1.108
		10	285.8Ab	193.87Ab	278.33Ab	303.6Aa	4.879
		20	238.2Ab	229.5Ab	286.33Ab	235.44Ab	3.546
		30	184.5Ab	217.0Ab	190.38Ab	256.02Ab	3.704
	S.E.M.		2.57	1.461	2.758	1.075	
	Soft	0	292.82Aa	95.96Bb	102.23Ba	70.50Ba	1.108
		10	141.86Ab	87.99Bb	55.21Bb	72.94Bb	4.879
		20	181.49Ab	105.94Aa	86.10Bb	64.14Ba	3.546
		30	288.48Aa	105.35Ba	87.58Ba	75.57Ba	3.704
	S.E.M		1.129	3.013	6.500	1.240	
Chewiness	Hard	0	1852.90Aa	213.35Ba	211.92Ba	288.42Ba	2.136
		10	232.17Ab	102.1Bb	100.9Bb	161.87Bb	5.909
		20	280.8Ab	277.69Aa	196.37Ba	159.10Bb	10.29
		30	156.74Ac	145.21Aab	163.79Aab	171.60Ab	13.27
	S.E.M.		19.858	1.9429	5.865	1.240	
	Medium	0	1129Aa	154.91Ba	85.18Ba	89.27Aa	9.566
		10	80.2Ab	67.76Ab	76.49Ab	80.29Aa	1.242
		20	63.4Ab	68.59Ab	62.26Ab	61.62Ab	9.380
		30	47.7Ab	45.39Ab	49.30Ab	45.63Ab	2.613
	S.E.M.		9.560	2.350	4.558	1.468	
	Soft	0	312.84Aa	37.81Ba	39.92Ba	24.74Bb	1.825
		10	50.9Aab	24.92Bb	32.79Ba	31.03Ba	1.035
		20	27.69Ac	21.74Bb	23.33Bb	21.70Bb	7.543
		30	89.Ab	21.73Bb	25.15Bb	17.06Bb	2.140
	S.E.M.		1.718	9.500	1.299	8.694	

[a] Means in the same row followed by the same letter (A-D) are not significant ($p<0.05$)
[b] Means in the same column followed by the same letter (a-d) are not significant ($p<0.05$)
[c] S.E.M., Standard errors of the mean (n=8).
[d] S.E.M., Standard errors of the mean (n=4)

CHAPTER 4

SENSORY CHARACTERISTICS OF MANGO FRUIT FROM THREE RIPENING STAGES AFTER OSMOTIC DEHYDRATION AND FROZEN STORAGE[1]

[1] Rincon, A. M., Kerr, W. L. To be submitted to *Journal of Food Quality,* 2004.

ABSTRACT

Moisture content, soluble solids and sensory fruit characteristics were studied to assess the effects of frozen storage on quality attributes mango slices from different ripening stages treated in osmotic solutions with different sucrose levels. Six descriptors for mango were derived after training sessions. These were: color, aroma, sweetness, sourness, firmness and juiciness. Significant differences ($P \leq 0.05$) were observed among the sucrose level concentration and from the ripening stages of the slices. For samples treated with the highest sucrose content, a higher moisture loss and sugar gain was reported. These results suggest that those samples were better protected against freezing-thawing damage, which was confirmed from the sensory panel.

Keywords: Mango, Sensory Evaluation, Frozen Storage, Texture, Thawing

Introduction

Mango fruits are relished for their succulence, exotic flavor, and delicious taste [1]. Mango (*Mangifera indica* L.) is a climacteric fruit [2], but highly perishable due to, among other causes, the activity of degradative enzymes (such as polygalacturonase and cellulase), which are activated in the maturation period, causing reduction of dietary fiber content [3] and softening of the fruit [4]. To maintain fruit quality throughout reasonably long periods, freezing, controlled temperatures and atmospheres of storage are required, which, in many cases, are not available in producing countries. In spite of this, mango is increasingly appreciated by consumers, not only as a fresh fruit, but also as an ingredient in processed products [5]. Organic acids and sugars are key components in the perception of mango flavor [6, 7].

Although freezing is used to preserve fruits more extensively, this process can result in reduced quality, due to undesirable physical, chemical and biochemical reactions which are irreversible [8]. During freezing, a part of the aqueous fraction freezes out and forms ice crystals that damage the integrity of the cellular compartments. The cellular membranes lose their osmotic status and semi-permeability [9]. The metabolic system of the plant tissue is interrupted, dislocation of the enzymatic system occurs and cell loses its turgor [10]. Undesirable changes in appearance, natural flavor and color caused by the freezing process on fruits is not in agreement with the increasing demand of consumers for the highest quality finished products [11]. In osmotic processes, dehydration can be applied as a pretreatment before freezing, removing part of the water from the product in order to decrease the amount of crystals formed during the freezing process. Minor damage of the cellular membranes occurs and therefore a better conservation of the fruit properties is assumed [10]. One possible method for mango processing

is osmotic dehydration as a pre-freezing technique with sugar solutions working at mild temperatures to preserve the product flavor along with other sensory properties [8].

Industry, trade, consumers and science have long been interested in possible quality changes in fruits due to freezing and subsequent thawing [12]. Appearance is the main quality factor that attracts the attention of consumers to frozen fruits. Visual judgment is made before a product is purchased and ultimately consumed. Odor and taste of frozen fruits are of prime importance, because consumers expect the characteristic fresh odor and taste of raw fruits [13]. Fruit texture, which is greatly influenced by freezing, frozen storage and thawing is also considered a very important factor to be evaluated for consumers. Consequently, substantial interest has developed in the objective scientific evaluation and measurement of the appearance, flavor and texture of frozen fruits [14-16].

The specific objectives of this research were, first, to develop a suitable vocabulary to characterize the sensory properties of mangoes. Next, this study involved the use of the generated attributes to assess how the sensory properties of mangoes treated with osmotic solutions containing different sucrose concentrations frozen for several weeks, were perceived by a trained panel.

Materials and methods

Sample preparation

Mango (*Mangifera Indica L.* Tommy Atkins var.) fruits from different ripening stages were purchased in a local market. The mangoes were manually washed with tap water, and classified based on three ripening degree levels: > 5 kg (firm), 3-4.9 kg (medium), and 0.2-2.9 kg (soft), as measured with a penetrometer (without skin) (Fruit pressure tester mod. FT 327, Instituto per la Valorizzazione dei Prodotti Agricoli, Italy). Each mango was peeled and cut into

slices (1.5 cm thick). A separate batch from each initial firmness level, without treatment, was vacuum packaged, frozen, and stored as a control. All the treatments were carried out at room temperature (20°C). Osmotic solutions of 10°, 20°, and 30°Brix were prepared with commercial sucrose. The following reagents were added to the syrups: ascorbic acid (Sigma-Aldrich, St. Louis, MO, USA) (0.1%), calcium chloride (Sigma-Aldrich, St. Louis, MO, USA) (0.25%), citric acid (J.T. Baker, Phillipsburg, NJ, USA) (0.5%), and sodium metabisulfite (Sigma-Aldrich, St. Louis, MO, USA) (500 ppm). The slices were immersed in the solution in a 1:25 (w/w) ratio (2.75 kg of fruit per batch), which was large enough to avoid significant changes in the concentration throughout the process [17]. Processing time was four hours for all treatments. This time was chosen on the basis of previous studies [18]. When the osmotic treatments were completed, the slices were drained and rinsed with cold tap water, then dried with paper towels before being placed into multilayer plastic films (CRYOVAC, Duncan, SC, USA). Air from the bags was removed, and the samples were sealed in a vacuum packaging sealer (Henkelmann, 600). The fruits were then frozen, and stored at -18°C for 20 weeks.

Analytical determinations

Moisture content was determined in duplicate by drying to a constant weight at 60°C (AOAC 20.013)[19]. The method for preparation of the fruit samples (AOAC 920.149) [19] was used prior to analysis of soluble solids concentration. Soluble solids were analyzed by measuring the refractive index of the prepared fruit juice samples with a refractometer (Bausch and Lomb, USA) at 23°C as room temperature (AOAC 932.14) [19].

Descriptive analysis

Sensory method

Sensory properties of the samples were evaluated using a method modified from the Spectrum® technique for descriptive analysis [20]. This procedure involves calibrating panelists based on standards established for the Spectrum® method, and rating samples using 150-mm structured line scales [7]. Each panelist rated the attribute intensity of each reference by first evaluating the reference for a particular attribute, then giving it an intensity rating between 0 and 150 on the line scales.

Panel and training

Volunteers for the sensory evaluation panels were recruited from students in the Food Science and Technology Department at the University of Georgia. Training was administered in ten one-hour sessions by the principal investigator. Panelists were asked to individually generate a set of descriptors for the appearance, texture, and flavor of mango, as indicated in previous studies [7, 21]. During subsequent discussions, a consensus vocabulary was derived by the group. All panelists were calibrated using standard references established by Spectrum analysis for sweetness, sourness, firmness, and juiciness parameters [20, 22]. Intensities of standards for color and aroma were assigned by panelists along the 150-mm line scale. For color, an intensity standard for hard (30-mm), medium (70-mm) and soft (130-mm) mango was assigned during training and discussion. The intensity standards for aroma were established by giving 75 mm (which is half of the line scale) to half ripe mango samples. The right half of the line measuring the intensity scale represented the aroma of mature mangoes, and a ripe mango control was ranked on the scale (110-mm). The left half of the line was a more raw, or green, mango aroma,

and a standard from this degree of ripeness was calibrated and placed on the line as an intense reference (40-mm).

Evaluations

The twelve treatments were evaluated over two sessions. Therefore, six samples were evaluated per morning session. A replicate of the evaluation was performed one week later, following the same procedure. The samples remained frozen for sixteen weeks (since the day of preparation), then; they were quickly thawed by placing the plastic bags in warm water. Once the samples were completely thawed, the vacuum sealed bags were opened, and the samples were rinsed with cold water and dried with paper towels. The samples were coded with 3-digit random numbers, and 20 g of mango slices were placed in each cup. Fresh solutions from references of sweet and sour descriptors were provided in each evaluation session.

Panelists rated samples individually in partitioned sensory booths. Score sheets were provided for each member of the panel, and they were required to rate the samples according to intensity ratings of the standards established during training. Unsalted crackers were served to cleanse the mouth between samples. Expectoration cups were also provided for each member of the panel.

Statistical analysis

The data was analyzed using the statistical analysis software, version 6.12 (SAS Institute, Cary, NC, USA). PROC MEANS was employed to calculate average and standard deviations of descriptive panel ratings. Significant differences between the means of initial firmness and Brix content from the treatments were determined by least significant difference ($P \leq 0.05$) [23, 24]. Student-Newmal-Keul's multiple range test was used to compare difference among mean values at $P \leq 0.05$ for moisture content and total soluble solids.

Results and Discussion

A total of 34 terms were developed by the panelists. The number of descriptive terms varied from 6 to 11 for each of the characteristics, and more descriptors were used for texture and aroma than for color and taste (Table 4.1). A final list of six parameters was developed and defined (Table 4.2). During the third day of training, panelists also determined references best represented the descriptive terms developed (Table 4.3). Panelists rated the attribute intensity of each reference by first evaluating the reference for a particular attribute, and then giving an intensity rating between 0 and 150 mm using a line. Ratings from each panelist were analyzed after each session. Standard deviations were used to assess panel performance. Based on empirical rules, the range of intensities assigned by most of the panelists to a treatment was within ±2 standard deviations from the mean [7, 25].

Osmotic dehydration

Table 4.4 shows the effects of osmotic dehydration in moisture content and total soluble solids after treatment and during freezing storage. It can be observed that the amount of total soluble solids significantly increased gradually based on the ripening stage thus, hard slices had the lowest values and soft slices has the highest amounts. This could be explained because free sugars, including glucose, fructose, and sucrose, generally increase during ripening; however, the sucrose content increases three- to four-fold due to the hydrolysis of starch [26]. Comparing the samples based on their sugar content, 0^{o}Brix slices showed significant differences at all firmness levels, but they did not develop soluble solids to the same level as the 10-30^{o}Brix slices. Osmotic treatment may be a cause of the greater solids uptake of the treated slices. this is may be due to the reduction of the particle size of the fruit to a certain level, above which solid gain is highly favored [27, 28]. Also, pretreatment with chemicals (SO_2), blanching, or freezing favors the solid

gain as compared to water loss because impregnation phenomena is enhanced, in that permeability increases and selectivity decreases [27-30]. Moisture content of slices significantly decreased as the sucrose concentration of the solutions increased. High concentration solutions reported lower amounts of water in hard, medium and soft mango slices than for mango slices treated in low concentration solutions. Tedjo and coworkers [31], showed that the moisture content of mango during osmotic treatment decreased with osmotic dehydration. The increased water loss from mango slices treated in 30^{o}Brix solutions could be explained because mass exchanges are favored by using high concentration solutions [30, 32-36]. These results showed that the mass transfer between mango slices and syrup solutions took place after four hours of treatment.

Color

There were significant variation throughout the ripeness of the fruit (hard, medium and soft), the sugar content (0^{o}, 10^{o}, 20^{o} and 30^{o}Brix) and panel performance (Table 4.6). ANOVA analysis also reported significant interaction effects of hardness*panelist, thus revealing that training has a significant impact on panel performance. For soft mangoes, the differences in color scores were significantly higher than medium mango, and at the same time, medium mango had a significantly higher value than hard mango (Table 4.7). The perception in changes in color from the panel could be due to the carotenoid content of mango fruit. Carotenoid composition tends to vary among mango cultivars, and it tends to increase as the mango ripens [14]. Significant variation for color was also detected, depending on the degree of sugar concentration of slices (Table 4.6). The syrup solutions contained ascorbic acid to retain color. Acidification of fruits that contain carotenoids might increase the color intensity of mango slices [24], the results of the panel showed that slices dipped in syrups, which ascorbic and citric acids were added, had

significantly higher values than slices not treated. These results agreed with those reported by Ramana and coworkers [37], where carotenoid retention of frozen mango pulp was compared with that of canned pulp with added ascorbic acid. After storage, a sensory panel reported significantly inferior values of the pulps with no ascorbic acid addition.

Aroma

Aroma is of prime importance for frozen thawed fruit especially because customers expect the characteristic of fresh odor of raw fruits [13]. Significant differences were observed in the sensory profiles of the three different initial ripening stages of the mango slices. Hard mango slices had lower intensity of mango aroma, meaning that the panel perceived a more skin like odor for those samples. As the initial ripening degree increased, (i.e. softer mangoes) aroma increased significantly on intensity values (Table 4.7). Furthermore, sugar level composition of the solutions affected the aroma intensity of the slices. Mean intensity from 0^{o}Brix mango slices were significantly lower than means from the treated slices (Table 4.6). That is, samples with greater concentration of sucrose had a greater 'ripe mango' aroma. Osmotic treatments and freezing have been reported to promote the formation of fruit aroma compounds that might prevent the quality loss associated with the volatile loss during frozen storage [10, 38]. However, different sugar compositions and treatments can change the final volatile profile in the frozen-thawed product [38].

Sweetness

Sweetness was the attribute that displayed the most sensory variation, showing significant differences for most of the factors analyzed (Table 4.5). The intensity values for sweetness increased significantly as initial ripening stage increased (Table 4.7). This can be explained by the general increase in free sugars, including glucose, fructose and sucrose, during ripening of

the fruits [26]. In fact, table 4.4 confirms a significant increase on soluble solids content as mango ripens. Sweetness intensity scores significantly increased as sucrose concentration increased on mango slices. All treatments were significantly different from one another, with 0^{o}Brix having the lowest intensity value and having 30^{o}Brix the highest (Table 4.6). The use of sugars and syrups with fruits is intended to enhance the natural fruit flavor [14]. Results from table 4.4 also agree with results from panel performance, meaning that osmotic dehydration treatments prior to freezing facilitated sugar gain during process and also during frozen storage.

Sourness

The presence of additional sucrose in mango slices had a significant effect on the perception of sourness. Those samples with more sugar were perceived as less sour, while samples with little or no sugar addition were ranked with higher values of intensity on the scale (Table 4.6). This could be due to the masking effect that sweet materials have on sour and bitter flavors. Thawed fruit that is not combined with sugar has a pronounced sour, disagreeable taste, which effectively masks fresh fruit flavor. There have been many statements in the literature that sugar or syrup addition is essential to preserve fruit flavor during storage [13]. The perception of sourness differed significantly between hard, medium and soft slices (Table 4.7). Medium slices had the highest sour intensity values, followed by hard slices, which were significantly lower, while soft mango reported the lowest intensity scores. In addition, there was a significant sugar content*panelist interaction for sourness perception (Table 4.4). By analyzing the means and standard deviations, it can be seen that, in general, treatments with 10^{o}Brix could be responsible for this interaction, because slices from this level presented high variation in sourness scores among panelists.

Firmness

For frozen pieces of fruit, the most serious defects caused by the freezing process are the adverse effects on texture and structural appearance [13]. In addition, freezing storage affects textural degradation of fruits by disrupting the cells as well as the life-supporting protective mechanisms of fruits [39]. Firmness scores showed significant differences between ripening stages for hard, medium and soft slices (Table 4.7). Although hard and medium slices were significantly different, mean firmness values were closer than those for soft mangos, where the differences were marked. Fruit cell walls, and, in particular, the middle lamella between cells, are rich in pectic substances. During ripening, de-esterification of pectins occurs, softening the fruit tissue [40]. This could explain the large differences in perceptions of firmness with initial ripeness. Sugar addition also affected the intensity of firmness (Table 4.6). Samples treated with 0^{o} and 30^{o}Brix syrups had significantly higher values than samples of 10^{o} and 20^{o}Brix. 30^{o}Brix slices were ranked with the highest intensity values due to the osmotic process. On table 4.4 it can be observed that 30^{o}Brix slices had significantly lower moisture content than the rest of the slices. This means that the dehydration process, removed a part of the water from those slices and thus, the amount of crystals formed during the freezing process was lower and a minor damage of the cellular membrane occurred. Sugars act by withdrawing water from the cells by osmosis, leaving very concentrated solutions inside the cells [14, 41, 42]. The high concentration of solutes depresses the freezing point, thereby reducing freezing within the cells. If the cells do not actually freeze, no ice crystals will form to cause structural damage [42]. Slices from 10 and 20^{o}Brix did not perform the same way, probably because the amount of sucrose present in the solutions was not sufficient to remove water and protect the internal tissues of the fruit against freezing damage.

Juiciness

Analysis of Variance (ANOVA) showed that there is significant variation in juiciness due to the ripeness of the fruit (hard, medium and soft) and the solution sugar content (0, 10, 20 and 30^{o}Brix) for juiciness intensity scores. Ripeness juiciness had significantly different values for hard, medium and soft slices. Soft mango was rated with the highest juiciness, which means that it released the highest amount of juice when bitten; however, juiciness was significantly lower when compared to medium and hard mango slices. The most important textural change, softening of the tissue, is brought about by structural alterations, both in the middle lamella and the primary cell wall, caused by enzymatic degradation and solubilization of pectic materials. These lead to cell separation and decreased resistance to applied forces. The observed physical changes primarily involve moisture loss and redistribution of the tissue, leading to a shriveled appearance and texture deterioration [39]. Table 4.4 shows that moisture content was lower for 30^{o}Brix samples while total soluble solids was higher, which means that more water came out from the slices and more sugar went into the mango tissue having more protection against the adverse effects of frozen storage. Fruit pre-treatment by osmotic dehydration before freezing has been reported as a tool in fruit cryoprotection, mainly due to the reduction of freezable water content [43], thus improving the texture characteristics of thawed fruits and vegetables [44].

Conclusions

Sweetness, firmness, color, and juiciness attributes intensified as sugar concentration increased. By analyzing moisture content and total soluble solids of mango slices it can be seen that the mass transfer process took place in the slices. This means that 30^{o}Brix slices were better protected against freezing damage because more water flowed from them and at the same time

more osmotic solute was transferred into the tissue, which was confirmed by panel performance. Sourness intensity scores tended to decrease as sugar concentration became more concentrated. This observation was attributed to the masking effect that sweet materials have on sour and bitter flavors [13]. Sweetness, juiciness, color, and aroma demonstrated increased rating scores as fruit was more ripen. The firmness attribute decreased as ripening degree increased. Sourness was rated higher in hard and medium slices, but low for soft slices. Significant interactions were observed for color, aroma, sweetness, sourness, and juiciness, implying that these factors are important to the overall quality of frozen-thawed mango slices.

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Table 4.1 Terms generated by the panelists

Characterisics	Terms
COLOR	Yellow (pale, Golden Bright) Green White Perfect Good Color Very Light Yellow-green
TASTE	Sweet Sour Bitter Acidic taste Low mango flavor Mild flavor Tart Melon-like flavor
TEXTURE	Hard Firm Soft Smooth-creamy Juicy Moist Fibrous Good texture for Ripe mangoes Adhesive Ripe mango Unripe mango Half ripe mango Crunchy
AROMA	Particular mango aroma Mild aroma Ripe smell Solid arona No off-aroma Sweet odor Vegetative odor Fruity odor Peach-like aroma Fresh aroma

Table 4.2 Terms used in the descriptive analysis of mango slices and their definitions

Attribute[a]	Definition
Color	
Green mango color	The intensity or strength of green color from light to dark green
Half ripened mango color	The intensity or strength of green-yellowish color from light to dark
Ripe mango color	The intensity or strength of yellow to orange color from light to dark.
Aroma	
Green mango aroma	The aromatic associated with green mango peel
Half ripened mango aroma	The aromatic associated with medium ripen mangoes
Ripe mango aroma	The aromatic associated with fully ripen mangoes
Tastes	
Sweet[b]	The taste associated with sucrose solutions
Sour[c]	The taste simulated by acids such as citric and malic
Texture	
Firmness[d]	The force required to compress the sample between the tongue and the palate
Juiciness[e]	The amount of wetness released from the sample when chewed

[a] Attribute listed in order perceived by panelists
[b,c] [45]
[d,e] [7]

Table 4.3 Standard references and intensities used in descriptive analysis of frozen-thawed mango slices.

Attribute	**Reference**	**Intensity[a] (mm)**
Color		
Hard mango	Hard mango slices[b]	30
Medium mango	Medium mango slices	70
Soft mango	Soft mango slices	130
Aroma		
Hard mango	Mango peel[c]	0
	Hard mango slices	40
Medium mango	Medium mango slices	75
Soft mango	Soft mango slices	110
	Mango Essence	150
Taste		
Sweetness	2.0% sucrose in deionized water[d]	20
	5.0% sucrose in deionized water	50
	16% sucrose in deionized water	150
Sourness	0.05% citric acid in deionized water[e]	20
	0.15% citric acid in deionized water	100
	0.2% citric acid in deionized water	150
Texture		
Firmness	Philadelphia Cream Cheese[f] (Kraft foods, Inc.)	10
	Franfurter (Hebrew national, Inc)	70
	Hard Candy (Kroger Co)	145
Juiciness	Crackers (Kroger, Co)	0
	Fresh Red apple	75
	Water	150

[a]Rated on a 150-mm unstructured line scale
[b,c]As determined by panel after training
[d,e,f,g][20]

Table 4.4 Total soluble solids content (g/100g pulp) and moisture content (g/100 g pulp) on mango pulp with different carbohydrates added stored at -18^{o}C±2.

Treatment	Initial Firmness	Sucrose Level	Storage Period (weeks)				S.E.M.[c]
			0	7	12	20	
TSS	Hard	0	6.60Bd	6.75Bc	11.40Ab	10.57Ac	0.906
		10	9.17Cc	11.86Ab	10.35Ab	10.64Ac	0.738
		20	12.34Ab	11.77Ab	12.99Ab	13.00Ab	0.462
		30	18.53Ca	17.9Ca	21.82Ba	23.23Aa	1.342
	S.E.M.		1.36	1.577	0.506	0.017	
	Medium	0	13.46Bb	14.68Bb	13.92Bb	15.89Ab	0.516
		10	11.42Ab	11.84Ab	13.03Ab	13.53Ab	1.006
		20	16.78Aa	19.40Aa	17.84Aa	18.60Aa	6.947
		30	16.09Da	19.43Ca	22.13Ba	24.69Aa	0.703
	S.E.M.[d]		1.71	5.554	1.440	0.465	
	Soft	0	17.41Ab	16.65Ac	16.65Ac	20.43Ac	2.561
		10	17.93Bb	19.43Bb	22.00Ab	22.15Ab	1.514
		20	19.80Cb	23.01Bb	26.12Ab	27.17Aa	0.611
		30	24.54Ba	25.42Ba	27.24Ba	27.83Aa	0.3552
	S.E.M.		1.92	1.007	1.893	0.218	
	Hard	0	0.87Aa	0.87Aa	0.87Aa	0.87Aa	0.000004
		10	0.83Ab	0.84Ab	0.83Ab	0.82Ab	0.0006
		20	0.82Ca	0.81Ab	0.82Ac	0.81Ab	0.00003
		30	0.79dA	0.79Ac	0.78Ad	0.78Ac	0.00002
	S.E.M.		0.0003	0.00002	0.00001	0.00003	
	Medium	0	0.87Aa	086Aa	0.86Aa	0.86Aa	0.0004
		10	0.83Ab	0.84Ab	0.83Ab	0.84Ab	0.00009
		20	0.82Ab	0.83Ac	0.81Ab	0.81Ac	0.00007
		30	0.78Ac	0.78Ad	0.78Ab	0.78Ad	4.22E-6
	S.E.M.		7.8E-5	3.4E-4	0.0012	4.2E-6	
	Soft	0	0.84Aa	0.83Aa	0.83Aa	0.83Aa	6.6E-5
		10	0.82Ab	0.82Aa	0.82Aa	0.82Aa	2.2E-5
		20	0.82Ab	0.82Ab	0.81Aa	0.81Ab	1.4E-4
		30	0.74Ac	0.75Ac	0.74Ab	0.74Ac	7.7E-5
	S.E.M.		1.6E-5	5.9E-5	4.3E-5	1.8E-5	

Table 4.5 Analysis of Variance for descriptive sensory attributes

Source of variation	Color	Aroma	Sweetness	Sourness	Firmness	Juiciness
Ripening Stage (RP)	*	*	*	*	*	*
Sucrose Concentration (SC)	*	*	*	*	*	*
Panelist(P)	*	*	*	*	*	*
SC*P	NS	NS	*	*	NS	NS
RP*P	*	NS	*	NS	NS	*
SC*RP	*	*	*	*	NS	*
RP*SC*P	*	NS	*	*	NS	*

Table 4.6 Sucrose effect on sensory rating

Sensory Attribute	Sugar Content				LSD (0.05)
	0	10	20	30	
Color	79.1[a] b	87.2 a	87.0 a	92.4 a	0.56
Aroma	65.2 c	78.4 b	82.6 ab	84.0 a	0.49
Sweetness	48.0 d	62.8 c	76.4 b	91.6 a	0.47
Sourness	46.2 b	53.7 a	38.4 c	37.2 c	0.50
Firmness	64.4 a	57.9 b	53.3 c	65.0 a	0.42
Juiciness	68.6 b	84.6 a	85.3 a	85.5 a	0.49

[a] Means in the same row within a sensory attribute followed by the same letter are not significantly different

Table 4.7 Ripening effect on sensory rating

Sensory Attribute	Sugar Content			LSD (0.05)
	Hard	Medium	Soft	
Color	66.7[a] c	83.6 b	109.7 a	0.48
Aroma	67.7 c	77.0 b	87.8 a	0.42
Sweetness	52.7 c	63.8 b	92.7 a	0.41
Sourness	50.7 b	55.6 a	25.3 c	0.43
Firmness	78.0 a	64.3 b	38.2 c	0.37
Juiciness	71.8 c	77.9 b	93.3 a	0.42

[a] Means in the same row within a sensory attribute followed by the same letter are not significantly different

CHAPTER 5

THE INFLUENCE OF CARBOHYDRATE COMPOSITION ON VITAMIN C STABILITY, PHASE AND STATE TRANSITIONS OF FROZEN MANGO PULP[1]

[1] Rincon, A. M., Kerr, W. L. To be submitted to *Journal of Fodd research International,* 2004

ABSTRACT

The effect of modification of the glass transition temperature (T'_g) through mango pulp formulation with different molecular weight carbohydrates on the ascorbic acid retention during storage at -18^{o}Brix was analyzed. The incorporation of different sugars into the mango pulps modified the distribution of sugars and their phase transitions.The highest protective effect of vitamin C degradation was obtained with maltodextrin M150 which reported the highest T'_g of the pulps. Also, Phase transitions of mango pulp in a large moisture content were determined by differential scanning calorimetry (DSC). From DSC traces, glass transition and melting temperatures were obtained and used to plot the diagrams for the five type of samples. The Gordon and Taylor was able to predict the dependence of the glass transition temperature on the moisture content. Before calorimetric analysis, samples were equilibrated under a wide range of different relative humidities (a_w 0.225-0.93) and sorption isotherms were determined. Experimental sorption isotherms agreed with previous results from similar research with fruits reported in the literature.

Keywords: Mango, Freezing, Drying, Glass Transition, Sugar Composition, Ascorbic acid, DSC, Sorption Isotherm, State Diagram, Water Activity.

Introduction

The physical state of foods, including that of sugars and biopolymers, has received increased attention because of its importance to food processing and storage [1, 2]. In the science of food polymers, one of the important properties used to characterize the physical state is the glass transition temperature, which involves transition from a 'glassy' to a 'rubbery' liquid-like state [2]. According to the concept introduced by Levine and Slade [3], the stability of frozen foods during processing and storage could be dependent upon the ability to store the food at a temperature lower than its glass transition temperature, or on the ability to modify the food's formulation to increase glass transition temperatures above storage temperatures [4]. This interpretation is believed to provide an enhanced physical characterization, thus allowing the specification of safer storage conditions for each material [5]. Dehydrated, low-moisture, and frozen foods are typically in an amorphous metastable state [1, 5-7], which is very sensitive to changes in moisture content and temperature [8]. A glass can be characterized by its phase transition, which occurs over a range of temperatures, between the onset and the endset. This second order transition is accompanied by an increased molecular mobility and a drastic drop in the elastic modulus, and can be measured by means of DSC (a change in heat capacity), DMA or dilatometry [9].

Water has a strong plasticizing effect on the food matrix [10]. A state diagram is obtained by plotting the glass transition temperature versus the moisture content of the product (glass transition curve) and the melting temperature [2]. Water activity and moisture content have been long considered relevant parameters to describe food stability, correlated through sorption isotherms [5]. There can be considerable hysteresis between the adsorption and desorption isotherms, which is mainly due to the non-existence of equilibrium of the vapor pressure inside a

food and its surroundings [9]. By combining information from both sorption isotherms and state diagrams, it is possible to construct food stability maps. These maps are useful in determining storage conditions for foods at which glass transitions are avoided or in determining how far a product should be dried in order to keep it stable under given storage conditions [9].

In the present study, the effect of the modification of the glass transition temperature (T_g), obtained through the pulp's formulation with different cryoprotectants (glucose, sucrose, Maltodextrin 150 and Maltodextrin 040 syrups), on the ascorbic acid during storage was analyzed. The influence of the addition of cryoprotectants to frozen mango pulp on chemical properties (soluble solids and acidity) was also studied. State diagrams and sorption isotherms for each treatment were determined in order to predict freezing storage conditions for the pulps.

Materials and Methods

Mango pulp

Mango fruits (*Manguifera Indica L.*) belonging to the variety Tommy Attkins were used in this research. These fruits were obtained from a local market. All the fruits had a similar degree of ripeness. The mangoes were washed and peeled, and five batches of 800 grams of pulp from fruits chosen at random were homogenized in a 12 speed Oster blender (Oster Corporation, Milwaukee WI, USA).

Glucose (J. T. Baker, Inc., Phillipsburg NJ, USA), commercial sucrose, maltodextrin 150 (Grain Processing Corporation, Muscatine IA, USA), and maltodextrin 40 (Grain Processing Corporation, Muscatine IA, USA) were used to prepare solutions of 40% (w/w). The polymer solutions were analyzed to obtain the glass transition of the matrix formed by the sugar and water and, therefore, to ascertain if the predominant transitions in the pulps were influenced by the presence of the sugar. Each treatment was prepared by homogenizing

fruit pulp in 500 g batches, which were combined with the previously prepared syrups. The formulation of the composites was 80% mango pulp and 20% sugar solution. For the control samples, the composite sample was prepared by mixing 80% mango pulp with 20% deionized water. After combination, pulps were stored in multilayer plastic films (CRYOVAC, Duncan SC, USA). Air from the bags was removed, and the bags were sealed in a vacuum packaging sealer (600, Henkelmann).

Freezing thawing treatments

After being packaged, the bags were frozen at -30^{o}C for 24 hours, then stored at -18^{o}C for six weeks. Thawing was carried out at room temperature (23 – 24^{o}C) overnight.

Analytical determinations

Moisture content was determined in duplicate by drying to constant weight at 60^{o}C (AOAC method 20.013) [11]. The method for preparation of fruit samples (AOAC method 920.149) [11] was used prior to analysis of the soluble solids concentration and titratable acidity. Soluble solids were analyzed by measuring the refractive index of the prepared fruit juice sample with a refractometer (Baush and Lomb, USA) at room temperature (Official method 932.14) [11]. AOAC method number 942.15 [11] was used to determine titratable acidity at room temperature. Ascorbic acid (vitamin C) was measured through 2,6-dichlorondophenol titrimetric method 967.21 [11].

Differential scanning calorimetry

Glass transition temperatures were determined by differential scanning calorimetry (DSC) (Perkin Elmer DSC 7, Norwalk CO, USA) on frozen-thawed pulps. The instrument was calibrated for heat flow and temperature using *n*-decane (Sigma chemical Co., St. Louis MO, USA) (m. p., -29.64 ^{o}C; ΔH_m, 201.82 J g^{-1}) and distilled water (m. p., 0^{o}C; ΔH_m, 333 J g^{-1}).

Perkin Elmer hermetically sealable 30 µl aluminum pans were used in all measurements, with an empty aluminum pan as a reference. Helium was used as a carrier gas. Nitrogen at a flow rate of 20 ml/min was used as a purge gas. The glass transition onset (T_{g1}) and the end point (T_{g2}) of the endothermal transition were determined [12, 13] For high moisture systems, the transition (T'_g) associated with the freeze concentration medium is more appropiate. All measurements were performed in triplicate.

High moisture products were cooled with dry ice to -85.0°C at 10°C min^{-1}, and scanned from -85.0°C to 30°C at 10°C/min to determine their thermal behavior in the non-annealed state. Isothermal annealing was performed at -45±2°C for pulps containing glucose, -35±2°C for pulps containing sucrose and plain pulps, -10±2°C for pulps containing maltodextrin M150 and -8±2°C for pulps containing maltodextrin M040. Next, high moisture products were re-cooled to -85°C at 10°C min^{-1}, and scanned again at -10 min^{-1}. At least three independent DSC scans were obtained for each sample processing treatment and moisture content. Low moisture samples were scanned from -85 to 125°C at a rate of 10°C/min.

Desorption isotherm

A desorption isotherm of mango pulp was determined at room temperature by exposing approximately 100 mg samples over saturated salt solutions for twenty days. Saturated aqueous solutions were employed to reach constant desired relative humidities (shown in parenthesis) in the desiccators: CH_3COOK (22.5%), $MgCl_2 \cdot 6H_2O$ (33%), K_2CO_3 (43%), $Mg(NO_3)2 \cdot 6H_20$ (52%), KI (64%), NaCl (76%), $(NH_4)_2SO_4$ (81%), and KNO_3 (93%). Equilibrium moisture contents were determined gravimetrically from the weight loss of the samples. Parameters for GAB (Guggenheim-Anderson-de Boer) equation (Eq 2.1) were fitted with the help of the

program Webb Tech (Wodonga, Australia; Dr. T.P. Labuza, University of Minnesota, St. Paul MN) Determinations were done in triplicate.

$$m = \frac{C_1 k m_o a_w}{(1 - k a_w)(1 - k a_w + C_1 k a_w)} \qquad \text{(Eq. 5.1)[14]}$$

where C_1 and k are constants, and m_o is the monolayer moisture content [14].

Prediction of glass transition temperatures

Glass transition temperatures of binary compatible polymer [5, 15] mixtures can be predicted via the empirical equation proposed by Gordon and Taylor (Eq. 2.2) [5]. The same equation is recommended to predict glass transition temperatures of water-food systems [5] [16].

$$T_g = \frac{X_s T_{gs} + k X_w T_{gw}}{X_s + k X_w} \qquad \text{(Eq. 5.2) [5]}$$

where, T_g, T_{gs}, and T_{gw} are glass transition temperatures of the sample, solid matrix, and water, respectively. X_s and X_w are the corresponding percent of solid and water contents, and k is an empirical parameter. The glass transition temperature of pure water was taken as T_{gw} = -135^{o}C [5]. Automated curve fitting software (TableCurve 2D, Jandel Scientific, San Rafael CA, USA) was used to fit the equation to the experimental data.

2.8 Experimental design and statistical analysis

The experimental design was planned using a complete factorial design. Four types of sugar (glucose, sucrose, maltodextrins M150 and M040) and a control (pulp with no sugar

addition) were evaluated six times (before treatments and once a week) during six weeks of storage. Analysis of variance was performed using SAS software (SAS Institute Inc., 2000), and the Student-Newman-Keul's multiple range test was used to compare differences among mean values. Mean values and pooled Standard Errors of the Mean (SEM) were reported, and the significance was defined at $P \leq 0.05$.

Results and discussion

Chemical parameters

Acidity and total soluble solids

There was no significant difference ($P<0.05$) in total titratable acidity of the pulps during frozen storage. However, there was a significant difference in total titratable acidity among the sugar composition of the pulps. Pulps with no sugar added showed significantly higher acidity values than treated pulps. Pulps treated with high molecular weight sugars reported higher acidity values than pulps treated with low molecular weight sugars (Table 5.1). The sugar addition during pulp processing modified the content of soluble solids in the pulps. Significant changes ($P<0.05$) were also present for pulps over time. For all pulps (except for the control pulp), there was a significant increase in soluble solids content during the six weeks of storage. This increase could in part be attributed to generation of sugars from reserve starch in the pulp [17, 18]. Mango pulp treated with maltodextrins had higher soluble solids content than pulps treated with lower molecular weight pulps, such as glucose and sucrose (Table 5.1).

Sorption isotherm

Sorption isotherms for control, glucose, sucrose, Maltodextrin M150 and Maltodextrin M40 samples are presented in Figures 5.1 to 5.5. Experimental data were fitted to the GAB (Guggenheim-Anderson-de Boer) model. GAB parameters are presented in Table 5.2. The shape

of the five mango pulp isotherms was similar to that of pineapple[19], persimmon [2], apple [5], and grape [20] previously obtained in a similar work.

DSC scans

Low relative humidity samples

The results of DSC analyses presented different behaviors for each water activity domain and for each treatment. In general, samples equilibrated at less than 81% relative humidity showed no ice formation on freezing; on rewarming, only one glass transition was observed, decreasing the value of T_g with increasing moisture content. The behavior was similar to that previously reported by Sa and Sereno [20] for onions, grapes and strawberries. Onset and endpoint glass transition temperatures, T_{g1} and T_{g2}, and their significant differences are given in Table 5.3 for pulp with no sugar added, as well as pulp with glucose and sucrose added. Table 5.4 includes data for pulp with added Maltodextrin M150 and Maltodextrin M040. The dependence of the onset glass transition (T_{g1}) on water activity was adequately described by a linear relationship: $T_{g1} = -110.47a_w + 29.852$ ($R^2 = 0.9258$) for control pulp; $T_{g1} = -93.935a_w + 38.213$ ($R^2 = 0.8436$) for glucose pulp; $T_{g1} = -136.73a_w + 38.332$ ($R^2 = 0.8826$) for sucrose pulp; $T_{g1} = -218.75a_w + 218.7$ ($R^2 = 0.9535$) for Maltodextrin 150 pulp, and $T_{g1} = -141.88a_w + 146.8$ ($R^2 = 0.9211$) for Maltodextrin M040 pulp. At low and intermediate moisture contents, the T_g values decrease linearly with increasing water activity. This linear relationship is of practical importance, since it allows the prediction of glass transition temperatures for materials exposed to various relative humidities [10, 21, 22]. In the hygroscopic domain ($a_w \leq 0.9$), the plasticizing effect of water is evident, with a great reduction of the sugar matrix T_g caused by increasing moisture content and molecular mobility.

Annealed samples

Ice melting was found in samples equilibrated at 93% relative humidity as well as in freshly prepared pulp prior to equilibration. An endothermic re-crystallization (devitrification) peak of unfrozen water, retained in the solid matrix due to very quick cooling of the sample during the freezing process, was observed [23]. This phenomenon was eliminated by annealing the sample [5, 24]. Optimum annealing conditions are obtained when the sample is held at T'_g for a considerable period of time, allowing the maximum amount of ice to be formed, and leading to a maximally concentrated solid matrix with moisture content equal to X'_g [20]. T'_g has been found to be a function of the composition of the mixture of sugars present in a sample where both the principal sugar and water act as plasticizer [25]. As T'_g was not exactly known in advance, and the principal sugar acts as a plasticizer, an annealing temperature close to T'_g for pure sugar solutions was used. Table 5.5 shows T'_g of sugars in solution, dry sugars, and values reported in the literature. As the principal sugar in mango is sucrose [26], it was expected that the main plasticizers for control pulp would be sucrose and water; therefore, the annealing temperature taken for that pulp was the same as that of sucrose pulps. Annealing temperatures used were as follows: -45±2^{o}C for pulps containing glucose, -35±2^{o}C for control and sucrose pulps, -10±2^{o}C for pulps containing maltodextrin M150, and -8±2^{o}C for pulps containing maltodextrin M040. As reported in the previous literature [5, 20, 27], isothermal annealing led to increased T_g values, elimination of the devitrification endotherm, a decrease in the melting temperature, and an increase in the size of the melting exotherm.

State diagrams and prediction of glass transition temperatures

State diagrams obtained for mango pulp samples are plotted in Figures (5.6-5.10). The glass transition curve of the sugar matrix in the hygroscopic domain is a theoretical glass curve [2, 28], and may be represented by the Gordon and Taylor model. This equation was fitted to the experimental values of T_g, by non linear regression with a curve fitting software (TableCurve 2D, San Rafael, CA), leading to the values shown on Table 5.6 using T_{gw} = -135.0 ^{o}C. These results reinforced the conclusion that T_g of fruit materials with high sugar content are related to the T_g values of the constituent sugars [21]. The melting temperature (T'_m) decreased with decreasing water content. T'_m determines the storage temperature below which all freezable water takes the form of ice crystals if supercooling does not occur [27]. The intersection of the extrapolated ice melting and glass transition curves should be expected to occur at T'_g. [2, 10, 20, 28]. A second order empirical polynomial equation fitted well the experimental points of T'_m for each pulp based on the results of Sa and coworkers [5], Sobral [2], and Chang [29] .

As expected, significant differences between the T'_g values of the different samples were found (Table 5.7). Low molecular weight sugar pulps had significantly lower T'_g values than did pulp with high molecular additives. Glass transition temperature has been found to be a function of composition [25]. Low molecular weight solutes, have a characteristic combination of low T'_g and high freezable water content. According to Martinez-Monzo and coworkers [27], this behavior converts low molecular weight sugars into monomeric cryoprotectants for frozen stored products with a desirable soft texture but a poor stability. The poor stability results from the relatively large ΔT (T_f-T'_g) [12]. Conversely, high molecular weight carbohydrates had high T'_g and lower freezable water content, meaning that those pulps had a shorter ΔT (T_f-T'_g), and, thus, they are more stable under frozen storage. These values for high molecular weight samples mean

that the growth of ice crystals during freezing could be greatly lower than the growth of ice for low molecular weight samples. The increase of the viscosity of the solution from pulps containing maltodextrins results in diffusion-limited ice formation [30]. This means that high molecular weight carbohydrates in pulps could change the texture of the pulp; however, they yield a desirable frozen stability, confirming that they are good cryostabilizers [27].

Effect of the modification on glass transition temperature on ascorbic acid retention

Considerable amounts of ascorbic acid may be lost during the processing and storage of food products. Temperature, pH, water activity, moisture content, and trace metals influence the degradation of vitamin C. Although there are different pathways for the degradation of ascorbic acid, aerobic and anaerobic, for a wide number of products, the reaction appears to follow first order kinetics [31]. A mathematical expression for this behavior as follows:

$$\left[\frac{C}{Co}\right] = e^{k_1 t} \qquad \text{Eq. 5.3}$$

where, k_1 is the first order reaction rate constant. Based on this equation, the data was fitted to an exponential model using Excel. A considerable decrease in ascorbic acid content took place initially during storage. This means that ascorbic acid losses started during processing of the pulps. Control pulps showed a higher amount of vitamin C content than pulps to which sugars had been added. Vitamin C degradation among the pulps was fitted into a first order kinetics model (Table 5.6). For pulps with no sugar added, the change in the amount of ascorbic acid as a function of time, the rate of degradation, was high, and the equation had an acceptable correlation. Pulps with sucrose reported similar behavior, showing a similar rate of decrease and correlation. Glucose and Maltodextrin M040 pulps did not follow the same pattern. The rate of

degradation for those samples was slower, and the correlation was very low. This poor correlation could be explained due to several pathways for degradation of ascorbic acid. Such pathways yield different breakdown products, thereby affecting the overall rates of vitamin C degradation [31]. Maltodextrin M150 was the pulp that showed the least correlation value among all the pulps. The amount of ascorbic acid in pulps treated with this Maltodextrin was lower as compared to control pulps; however, the rate of degradation was almost constant over time. This means that, although there were initial losses due to treatment, Maltodextrin M150 was able to maintain a relatively constant amount of vitamin C in the pulps, over time.

The lower ascorbic acid degradation rates for Maltodextrin M150 could also be related to the observation that this fruit has the highest T'_g (Table 3.7), hence the lower (T - T'_g) values, and, as a consequence, could have the lowest structural collapse during storage [4]. This could have affected phenolase activity, and, thus, the ascorbic acid degradation rate [32]. The incorporation of high molecular weight carbohydrates into mango pulp modified the low temperature transitions, and significantly increased vitamin C stability during frozen storage at -18^{o}C. These results agree with those reported by Torregianni [32] for kiwi fruit pre-treated in maltose, which had the highest T'_g values, and, thus, the highest chlorophyll and vitamin C retention during frozen storage. It has been hypothesized that T'_g cannot be used as an absolute reference when comparing enzymic activity in frozen systems with different sugar compositions [4] [33]. As reported by Lim and Reid [34], knowing only the T'_g of a polymer is not enough to determine whether the polymer would be an adequate cryostabilizer for a frozen system [4]. This conclusion is confirmed in our data, where pulps treated with Maltodextrin M040 demonstrated similar T'_g values to Maltodextrin M150, but differing ascorbic acid stability during storage.

Conclusions

T'_g has been found to be a function of the composition of the mixture of sugars present in a sample where both the principal sugar and water act as plasticizers [25]. The results obtained confirmed that addition of different molecular weight sugars to mango pulp caused modification of the glass transition temperature. As the molecular weight of the sugars used for pulp formulation increased, so did the T'_g values. After six weeks of storage, there was no significant change in acidity of the pulps. Soluble solids content changed with pulp formulation with different sugars. A substantial loss of ascorbic acid content was observed after processing of the pulps and after six weeks of storage. The highest protective effect of ascorbic acid degradation was obtained with Maltodextrin M150, which reported the highest T'_g of the pulps, hence lower $T - T'_g$ values. High molecular weight carbohydrates seemed to improve the resistance of mango pulp to freezing injuries, while low molecular weight sugars did not enhance frozen stability as much, probably because of the presence of a greater amount of freezable water which did not limit the growth of ice crystals.

Measured sorption isotherms agree with similar work previously done for fruits [2, 5, 19, 20]. In this study, it was possible to determine glass transition temperatures. Differential scanning calorimetry was an adequate method to determine glass transition temperatures in formulated pulps, leading to the formation of state diagrams for those materials. These diagrams had similar characteristics to those previously reported for similar fruits and vegetables [2, 5, 20]. Annealing was necessary to achieve maximum ice formation on the high moisture content samples. The empirical Gordon-Taylor equation was able to predict the dependence of T'_g on moisture content.

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Table 5.1 Effect of sugar composition on acidity (g citrin acid/100g pulp), pH and total soluble solids (g/100gpulp) in mango pulps stored at -18±2°C[ab]

Treatment	Sugar	Storage time							S.E.M.[c]
		0	1	2	3	4	5	6	
Acidity	Control	0.34Aa	0.30Aa	0.33Aa	0.31Aa	0.32Aa	0.33Aa	0.30Aa	0.001
	Glucose	0.26Ab	0.21Ac	0.20Aa	0.22Abc	0.22Aa	0.27Aa	0.23Ac	0.002
	Sucrose	0.22Aab	0.19Ac	0.18Aa	0.17Ac	0.19Aa	0.23Ab	0.21Ac	0.007
	M150	0.29Aa	0.28Ac	0.27Aa	0.31Aa	0.284Aa	0.30Aa	0.29Aa	0.001
	M040	0.29Aa	0.25Ab	0.24Aa	0.26Aab	0.27Aa	0.27Aa	0.26Aab	0.004
	S.E.M.	0.002	8.5 E-5	0.001	0.0003	0.003	0.0004	0.001	
Total soluble solids	Control	7.72Ac	6.40Bd	6.49Ad	8.77Ac	8.57Ac	8.80Ac	8.99Ac	2.52
	Glucose	12.06Bb	10.62Bc	11.02Bc	11.97Bb	11.92Bb	12.42ABb	13.87Ab	0.30
	Sucrose	14.40Ba	13.92Bc	14.06Bb	14.77Ba	14.06Ba	14.06Ba	15.33Aa	0.08
	M150	16.85Ba	15.45Bb	15.84Bb	15.06Ba	15.36Ba	16.05Ba	17.61Aa	2.81
	M040	17.00ABa	16.79Ba	16.49Ba	16.99Ba	16.60Ba	17.30Aa	17.42Aa	1.55
	S.E.M.d	0.80	0.26	0.37	3.49	0.40	3.72	1.12	

[a]Means in the same row followed by the same letter (A-B) are not significantly different ($P<0.05$)

[b]Means in the same column followed by the same letter (a-c) are not significantly different ($P<0.05$)

[c]S.E.M., standard errors of the mean (n=14)

[d]S.E.M., standard errors of the mean (n=5)

Table 5.2 GAB parameters for pulps with different sugars added

Sugar	***K***	***C***	m_o **gH$_2$O/gsolid**	r^2
Control	0.89	557.95	0.275	0.92
Glucose	0.98	4.94	0.113	0.99
Sucrose	0.99	8.49	0.082	0.99
M150	1.00	200.00	0.069	0.97
M040	0.99	3.36	0.069	0.99

Table 5.3 Glass transition temperatures (T_{g1} ans T_{g2}) of frozen-thawed mango pulps with addition of Glucose and sucrose and equilibrated at different water activities

Water Activity	**Glass transition temperatures in ^{o}C**					
	Control		Glucose		Sucrose	
	Onset (T_{g1})	End (T_{g2})	Onset (T_{g1})	End (T_{g2})	Onset (T_{g1})	End (T_{g2})
0.22	0.26±1.9	23.06±2.58	0.47±1.48	10.42±2.04	6.30±3.92	34.34±4.03
0.33	-8.7±1.02	13.71±1.02	-6.01±0.11	1.13±3.39	0.18±2.34	20.13±4.42
0.43	-13.1±1.02	12.01±2.8	-18.34±1.12	-5.48±2.61	-11.66±5.19	8.71±4.69
0.52	-24.8±2.49	-10.79±1.77	-25.22±4.6	-19.00±4.59	-53.95±1.41	-26.17±10.4
0.69	-39.8±0.31	-33.05±2.18	-27.49±2.45	-23.48±3.11	-58.83±7.84	-17.01±7.5
0.76	-49.1±5.21	-39.74±6.13	-40.41±1.37	-32.90±4.92	-	-
0.81	-72.4±3.48	-67.99±3.13	-70.75±1.07	-68.14±5.03	-64.14±4.20	-59.50±0.4

Table 5.4 Glass transition temperatures (T_{g1} ans T_{g2}) of frozen-thawed mango pulps with addition of Glucose and sucrose and equilibrated at different water activities

Water Activity	**Glass transition temperatures in ^{o}C**			
	Maltrin M040 Onset (T_{g1})	Maltrin M040 End (T_{g2})	Maltrin M150 Onset (T_{g1})	Maltrin M150 End (T_{g2})
0.22	-	-	-	-
0.33	-	-	95.44±5.03	114.00±3.93
0.43	116.50±3.98	124.43±4.63	84.96±1.18	107.70±1.59
0.52	115.63±3.34	115.92±4.71	75.29±3.67	95.90±4.71
0.69	64.84±32.8	103.10±4.34	61.51±12.5	84.48±3.85
0.76	51.87±11.2	72.74±4.25	39.50±2.0	79.40±9.8
0.81	40.71±0.93	69.27±7.6	20.71±0.93	72.27±0.5

Table 5.5 Glass transition temperatures (T'_g) for pure compounds and solutions as determined by DSC

Sugar	T_g (^{o}C) dry sugar onset	T'_g (^{o}C) Solution onset	T'_g (oC) obtained for solutions	SD[d]
Glucose	31[ab]	-57[a], -43.5[c]	-43.47	1.97
Sucrose	62[b]	-46[b], -33.5[c]	-33.387	3.86
Maltrin M150	140[e], 99[f]	-13.0[c]	-11.375	0.21
Maltrin M040	188[g]	-15.0[e]	-15.435	0.95

[a] [12]
[b] [25]
[c] [33]
[d] Standard deviation of experimental prepared solutions as determined by DSC
[e] [22]
[f] [35]
[g] [36]

Table 5.6 Gordon and Taylor parameters for mango pulps with different sugars added

Sample	***k***	T_{gs} (°C)	r^2
Control	1.80	50.00	0.78
Glucose	2.12	50.00	0.91
Sucrose	6.2	81.29	0.95
M150	1.62	139.19	0.93
M040	1.31	147.84	0.99

Table 5.7 Onset melting temperature (^{o}C) for mango pulp treated with different sugars on the high moisture content.

Water activity	Sugar	T'_g ^{o}C
0.93	Control	-49.72 c
	Glucose	-30.71 b
	Sucrose	-38.22 c
	M150	-22.98 a
	M040	-23.02 a
	S.E.M.	38.89
	Control	-30.28 b
Fresh	Glucose	-37.10 b
	Sucrose	-30.67 b
	M150	-13.30 a
	M040	-17.27 a
	S.E.M.	7.73

Means in the same column followed by the same letter (a-c) are not signficantly different

Table 5.8 First order kinetic parameters for Ascorbic acid degradation and T'_g (^oC) values of mango pulp after storage at -18±2^oC for six weeks

Sugar	T'_g (^oC)	**First order kinetics parameters**		
		k (-s)	Co	r^2
Control	-30.2	$-3.01*10^{-5}$	30.77	0.77
Glucose	-37.1	$-1.01*10^{-5}$	24.204	0.25
Sucrose	-30.6	$-3.03*10^{-5}$	31.687	0.75
M150	-13.3	$9.08*10^{-7}$	18.118	0.0081
M040	-17.2	$-1.04*10^{-5}$	22.928	0.38

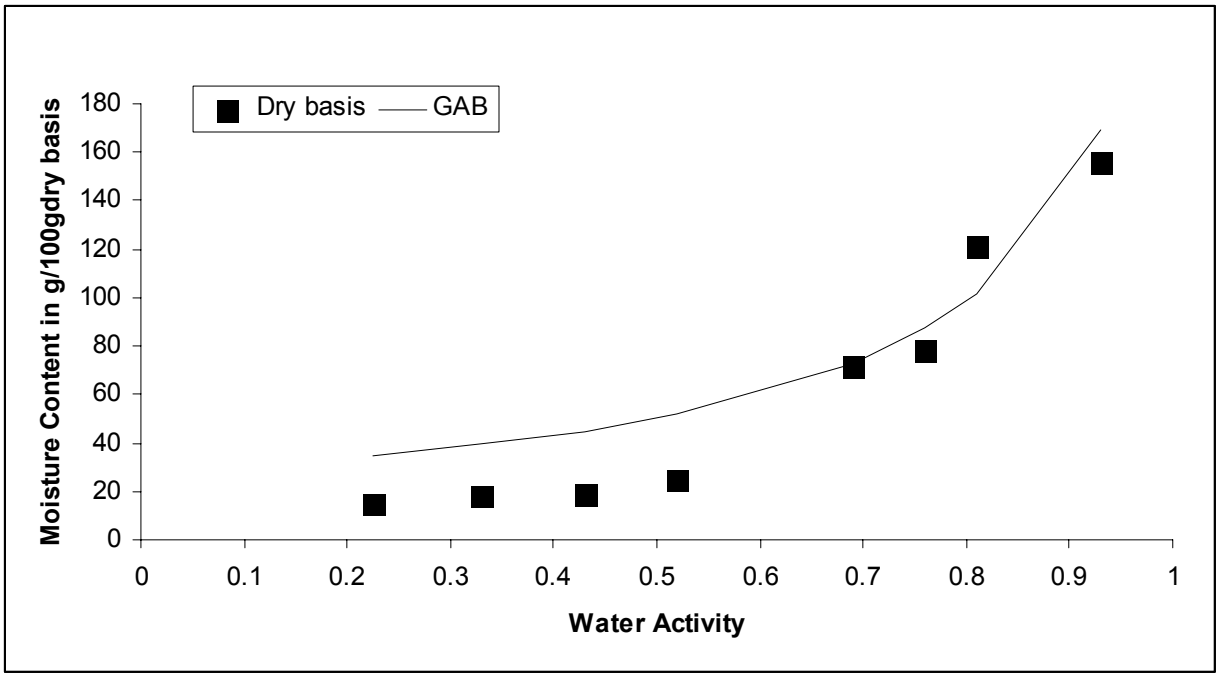

Figure 5.1 Sorption isotherm of mango pulp with no sugar added.

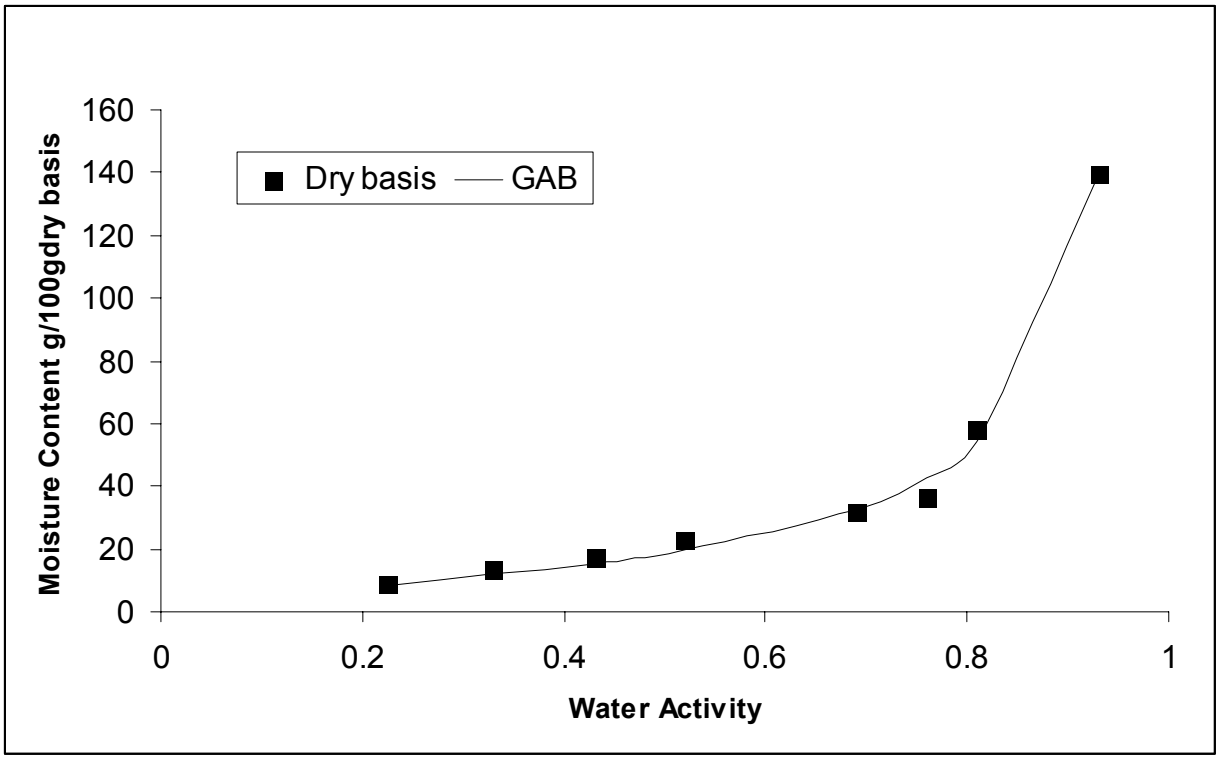

Figure 5.2 Sorption isotherm of mango pulp with glucose added.

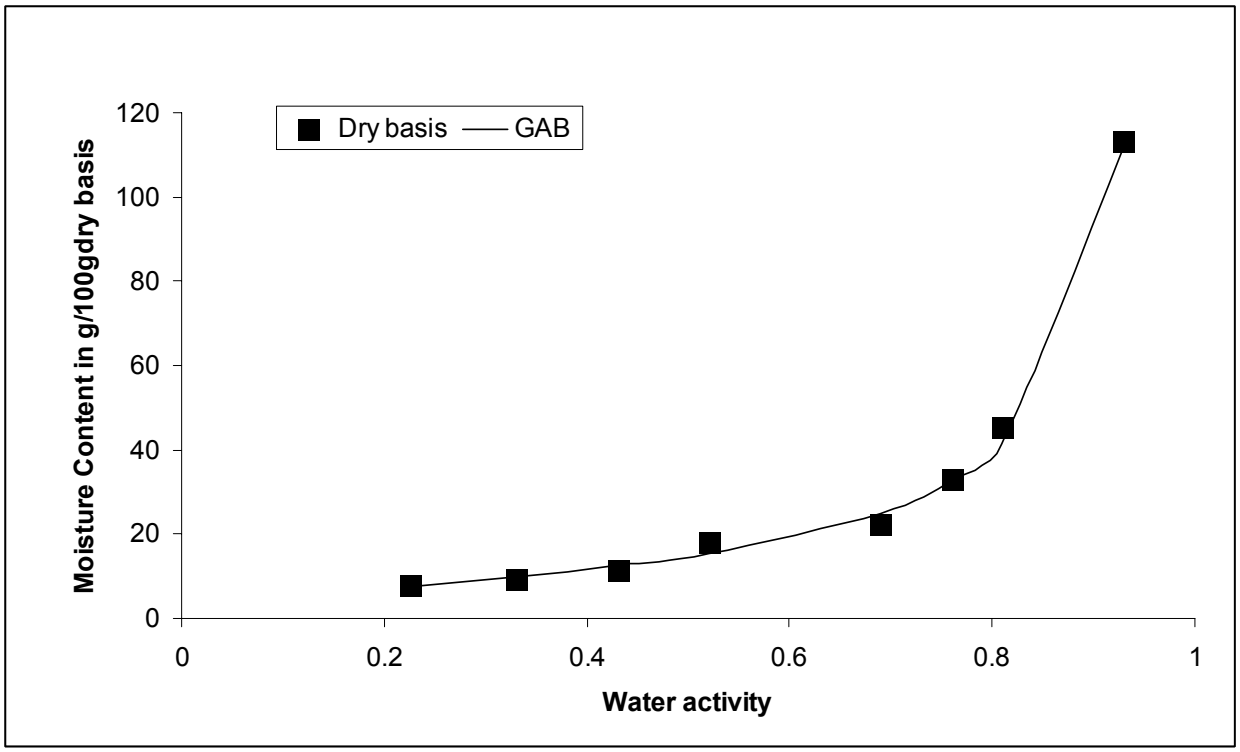

Figure 5.3 Sorption isotherm for mango pulp with sucrose added.

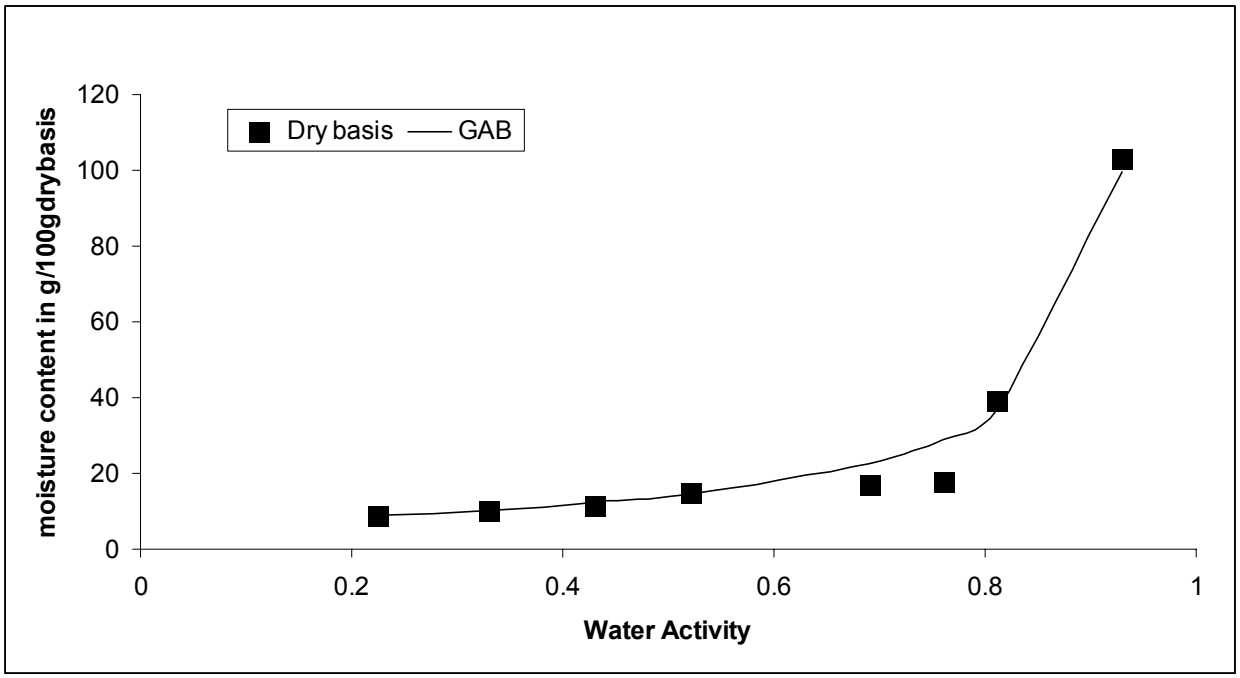

Figure 5.4 Sorption isotherm of mango pulp with Maltodextrin M150 added.

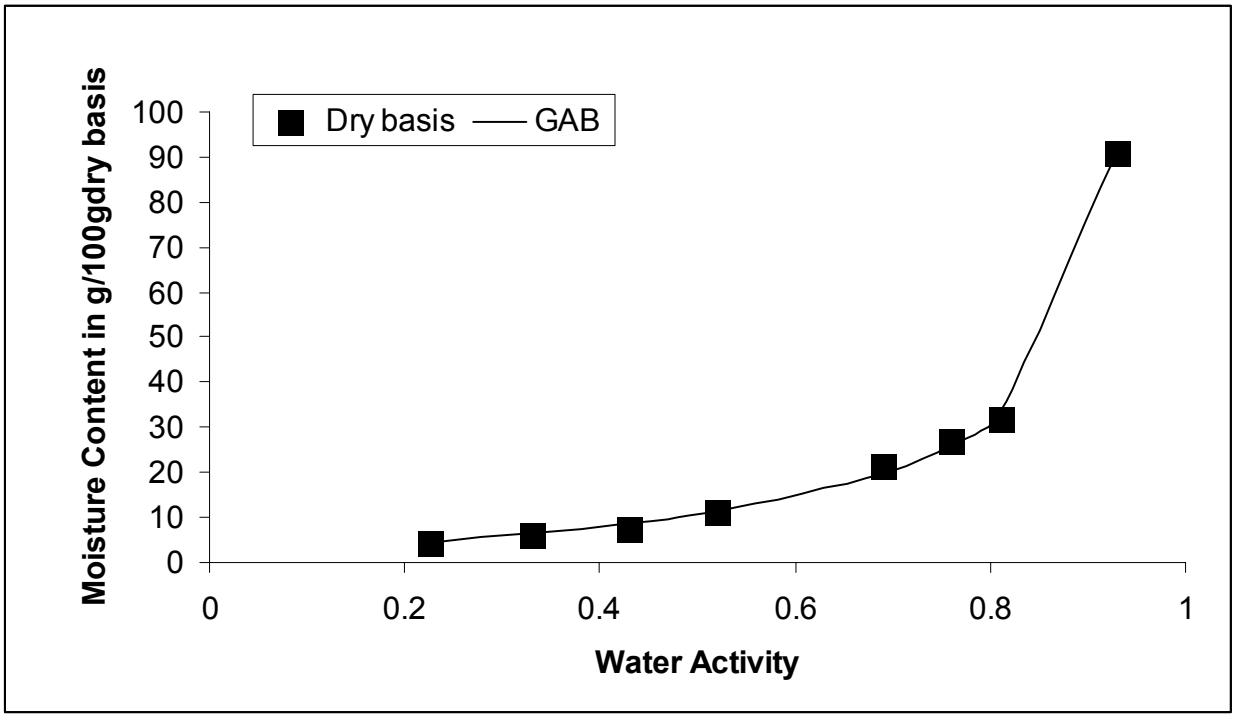

Figure 5.5 Sorption isotherm for mango pulp with Maltodextrin M040 added.

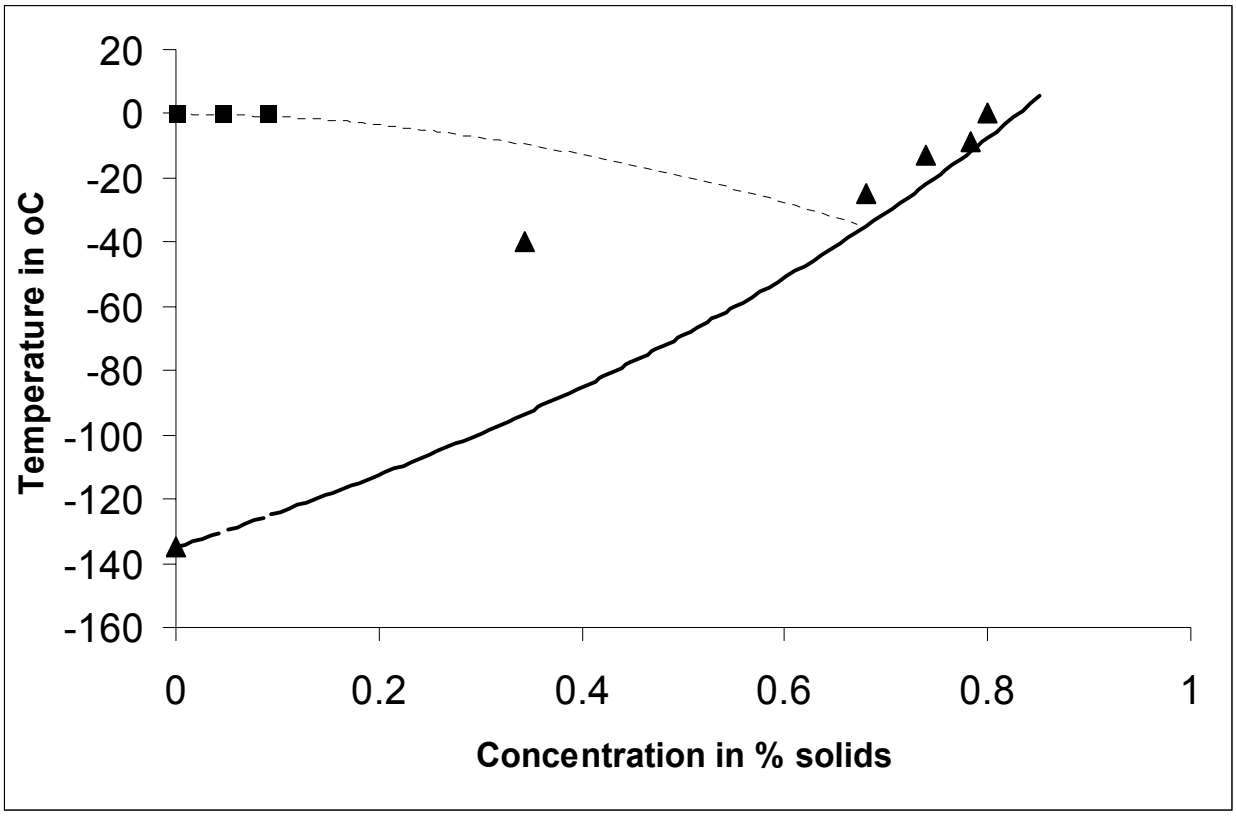

Figure 5.6 State diagram for pulp with no sugar added. (▲) T'_g mango pulp, (■) T_m mango pulp, (- - -) Melting curve, (—) Gordon and Taylor Equation.

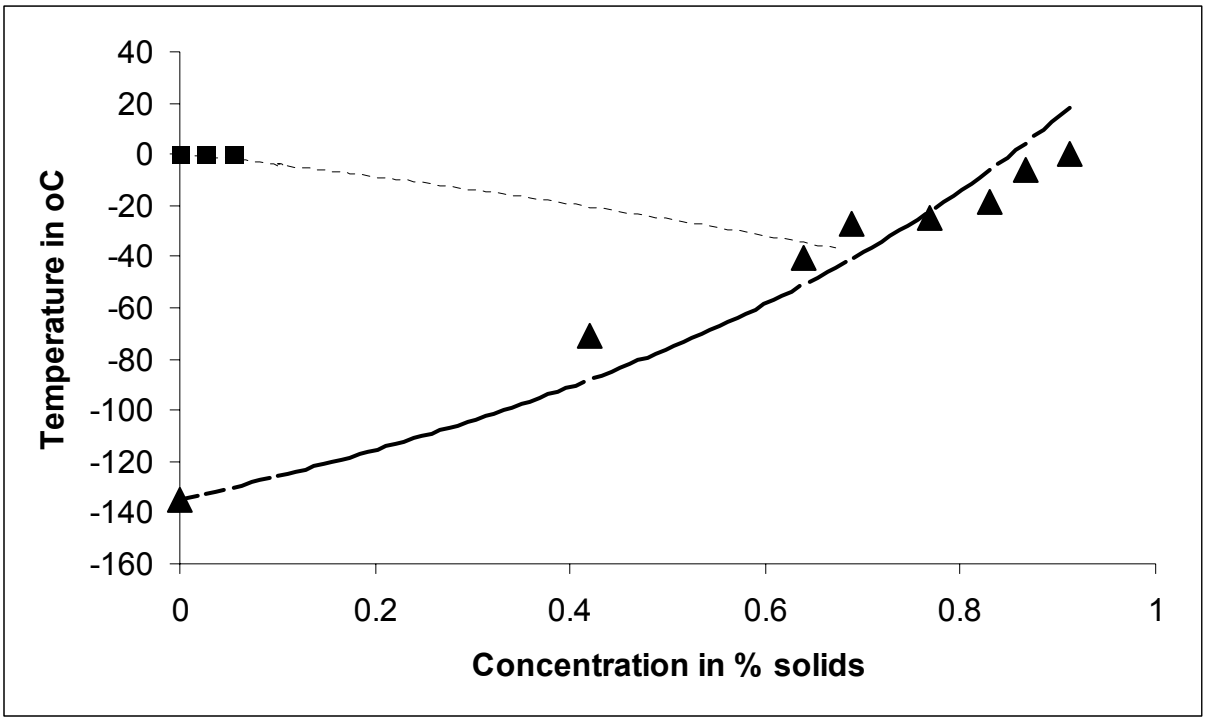

Figure 5.7 State diagram for pulp with glucose added. (▲) T'_g mango pulp, (■) T_m mango pulp, (- - -) Melting curve, (—) Gordon and Taylor Equation

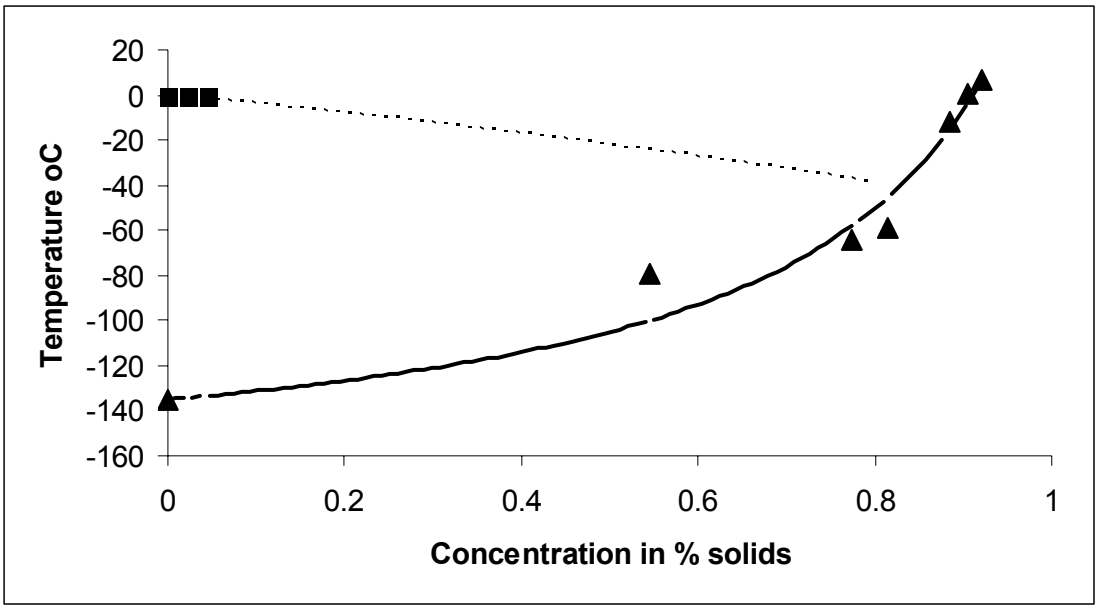

Figure 5.8 State diagram for pulp with sucrose added. (▲) T'_g mango pulp, (■) T_m mango pulp, (- - -) Melting curve, (—) Gordon and Taylor Equation

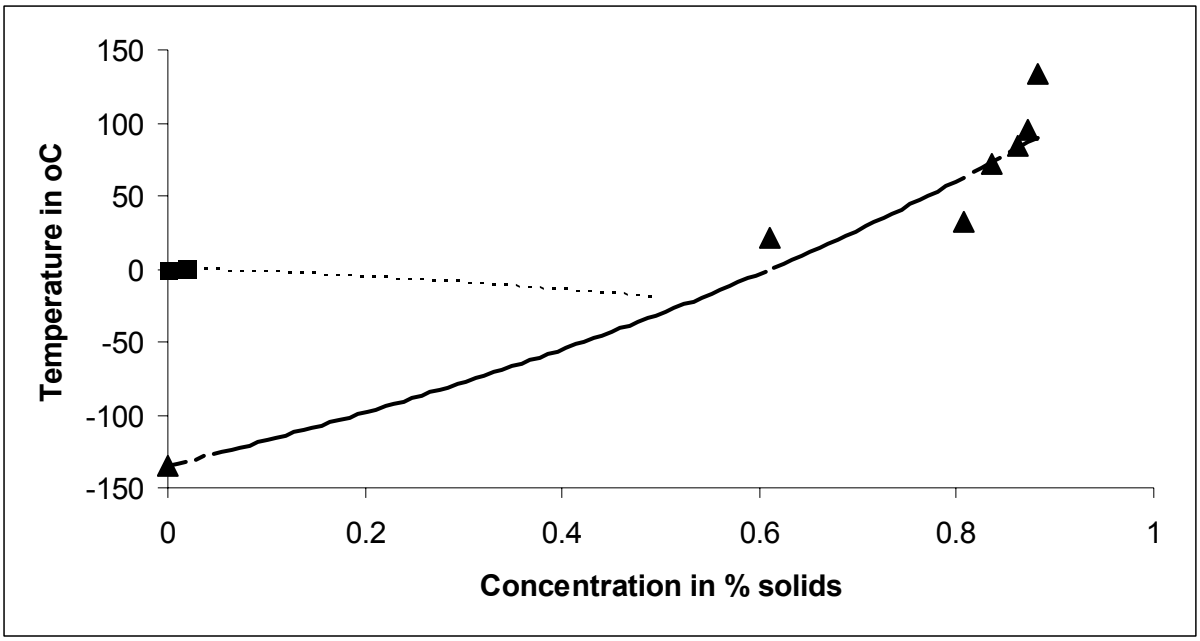

Figure 5.9 State diagram with Maltodextrin M150 added. (▲) T'_g mango pulp, (■) T_m mango pulp, (- - -) Melting curve, (—) Gordon and Taylor Equation

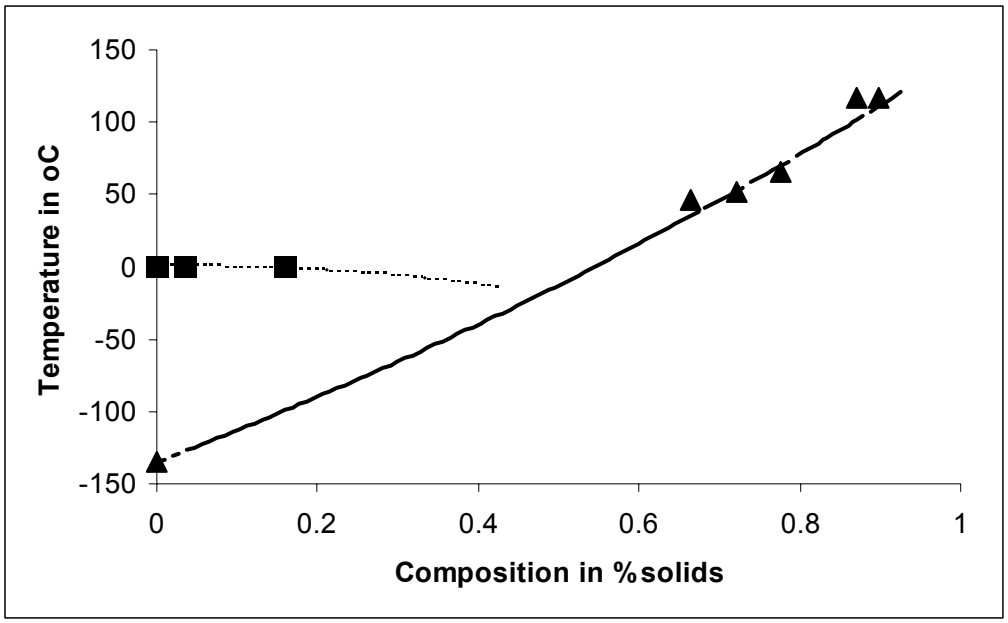

Figure 5.10 State diagram for pulp with Maltodextrin M040 added. (▲) T'_g mango pulp, (■) T_m mango pulp, (- - -) Melting curve, (—) Gordon and Taylor Equation

CHAPTER 6

CONCLUSIONS

The first part of the study involved minimization of adverse effects of freezing in quality of mangoes (*manguifera indica L.*) var. Tommy Atkins from different ripeness degrees using osmotic dehydration as a pretreatment. It was shown that osmotic treatments and freezing storage reduced quality in all physicochemical, optical and mechanical parameters analyzed compared to initially fresh mango. However, the presence of sugars and preservatives provided more protection against freezing damage for treated slices than for untreated ones over storage time. 30^{o}Brix slices, the highest concentration used, provided better protection against freezing damage because this concentration induced the highest sugar gain-water loss ratio thus, better freezing damage protection of mango tissue.

In the second part of the study, sensory analysis of osmotically dehydrated mango slices treated before freezing were evaluated with a trained panel after several weeks of storage. The results showed that sweetness, firmness, color and juiciness attributes had higher intensity scores as sugar concentration of the slices increased. On the other hand sourness intensity scores significantly decreased as sugar concentration on the slices became higher. This observation was attributed to the masking effect that sweet materials have on bitter and sour flavors [1]. The results also showed that the higher the sucrose concentration used, the higher moisture loss and solid gain took place in the slices. This explains why 30^{o}Brix slices showed higher intensity values for firmness and sweetness.

Finally, the glass transition temperature was found to be a function of the composition of the mixture of carbohydrates present where both the principal sugar and water were the main plasticizers. As the molecular weight of the carbohydrates used for pulps formulation increased, so did the T'_g. The highest protective effect on ascorbic acid degradation was obtained with Maltodextrin M150, which reported the highest T'_g, hence lower T_f- T'_g values. Related to storage stability study, it was found that measured sorption isotherms were similar to those obtained from similar experiments with different fruits. Glass transition temperatures and associated phase characteristics were determined by differential scanning calorimetry and state diagrams were obtained. The Gordon and Taylor could adequately represent the dependence of T'_g on moisture content of the samples.

Osmotic dehydration pre-treatments were able to modify physicochemical parameters such as vitamin C and titratable acidity as well as; optical and mechanical parameters. Treatments carried out with the highest osmotic solution concentration (30^oBrix), improved significantly the quality of the mango slices after freezing in terms of color and mechanical parameters as well as sensory analysis. However, negative effects from osmotic processing were observed before freezing as the results from all quality parameters were compared to fresh mango from all ripening stages.

Based on this study, the incorporation of cryoprotectants (carbohydrates with different molecular weights) to mango tissue greatly affected overall quality of the fruit. Also, the glass transition temperature was confirmed to be a function of the composition of the pulp. However, knowledge of T'_g alone is not sufficient to determine whether the cryoprotectant would be a good cryostabilizer or not as hypothesized by Lim and Reid [2], Kerr [3] and Nicoli [4]. Texture and

sensory evaluation should be used to evaluate the influence of the cryoprotectant addition on these quality parameters.

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