Osmotic dehydration technique for fruits preservation—A review

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Abstract
Fruits are important sources of vitamin and minerals. They are got rotten before the final consumption due to lack of preservation and storage facilities. Osmotic dehydration is an operation used for the partial removal of water from plant tissues by immersion in an osmotic solution. This is a useful technique to extend the shelf life and decrease the energy cost. It also helps to improve the sensorial, nutritional and organoleptic properties of foods. Along with freezing and deep fat frying make the better quality final product. It results in little bit loss of aroma in dried and semidried foods. Osmotic dehydration has become more popular in food processing industry.

Key words: Preservation, extend shelf life, dehydration

Introduction
Fruits are important sources of digestible and indigestible minerals, carbohydrates and certain vitamins, particularly vitamins A and C. The moisture in most of the fruits above 75% and fruits are prone to spoilage by molds and yeasts (Janisiewicz et al., 1999). The essential amounts of vitamins, protein, minerals, dietary fiber and calories that provide the nutritional values are predictable and documented (Salunke et al., 1991). Fruits and vegetables are produced during peak seasons but due to lack of preservation and storage facilities, the market become overstocked during such periods and get rotten prior to reach the final consumer.

Osmotic dehydration (OD) is one of most important complementary treatment and food preservation technique in the processing of dehydrated foods, since it presents some benefits such as reducing the damage of heat to the flavor, color, inhibiting the browning of enzymes and decrease the energy costs (Alakali et al., 2006; Torres et al., 2006). Osmotic dehydration results in increased shelf-life, little bit loss of aroma in dried and semidried food stuffs, lessening the load of freezing and to freeze the food without causing unnecessary changes in texture (Petrotos and Lazarides, 2001). It has been reported that osmotic dehydration reduced up to 50% weight of fresh vegetables and fruits (Rastogi and Raghavararo, 1997).

Osmotic dehydration involves the immersion of foods (fish, vegetables, fruits and meat) in osmotic solution such as salts, alcohols, starch solutions and concentrated sugars, which some extent to dehydrates the food (Erle and Schubert, 2001). Different types of solutes such as fructose, corn syrup, glucose, sodium chloride and sucrose are used as osmotic agent for OD (Azuara and Beristain, 2002). Low molar mass saccharides (sucrose, glucose and fructose) make easy the sugar uptake due to high diffusion of molecules. It has proved to be a good quality method to get modestly processed fruits, due to the much sensory resemblance between the natural and dehydrated products (Sousa et al., 2003).

The influence of osmotic dehydration which has much paid attention on the solute kinetics or water swap inside and outside of food tissues (Giraldo et al., 2003), the application of vacuum pulse during osmotic treatments and special sound effects on impregnation time (Mujica-Paz et al., 2003). The diffusion of water is effected to natural substances such as acids, vitamins, minerals, colorants and saccharides (Lombard et al., 2008). But this flow is quantitatively negligible. Osmotic dehydration which improves the sensorial and nutritional properties, preserve and improve the organoleptic properties of foods. It is efficient in room temperature. In food processing industry, osmotic dehydration has become more popular (Tortoe et al., 2007).

The different types of osmotic agents such as glucose, sorbitol, sucrose and salts are used according to the final products (Singh et al., 2008). However combination of different solutes can be used (Taiwo et al., 2003). Water loss from vegetables and fruits took place in first two hours and maximum sugar gain within 30 minutes (Conway et al., 1983). Osmotic dehydration is used with other drying methods such as freezing and deep fat frying to make available better quality final product (Torreggiani and Bertolo, 2001a; Behsnilian and Speiss, 2006). Temperature and concentration of osmotic syrups increased the rate of water loss during OD. However higher temperature has the significant effect on the structure of tissues (Lazarides, 2001) and cause flavor deterioration and enzymatic browning at temperature above 45°C.

Along with osmotic dehydration, freezing is another important method. Fruit freezing can be resulted to change in color, flavor and texture of fruits as well as to maintain enzyme activity. Freezing of fruits can be resulted in decrease quality, due to poor texture and enzymatic browning action (Tregunno and Goff, 1996). The frozen products can be stored at temperature of -29°C in Europe to maintain the quality of frozen products. At a temperature of -18°C or lower can stop the products from microbiological damages, if the temperature fluctuation is not wide (Buckle et al., 2007).
Osmotic dehydration (OD) of foods (Pointing History of osmotic dehydration (Torregianni and Bertolo, 2001). Other steps of fractional dehydration allowed tissues (Huxon, 1982). Freezing has stabilizing effect, chemical and physical measures of freezing the fruit to avoid the cellular structure loss, that caused by chemical and physical measures of freezing the fruit tissues (Huxon, 1982). Freezing has stabilizing effect, other steps of fractional dehydration allowed nutritional, sensory, structural and functional characteristics of raw material to be customized (Torregianni and Bertolo, 2001).

**History of osmotic dehydration**

Pointing and coworkers in 1966 were pioneering the research on OD of foods (Pointing et al., 1966), and since after that a continuous stream of publication was appeared (Rastogi et al., 2002). By using of osmosis process 50% of original weight of fruit was reduced, after that it was subjected to freeze or vacuum dried. Monograph of apple was calculated the drying rate of osmotic dehydration provided by Farkas and Lazar (1969). Vial et al. (1991) and Heng (1990) studied the OD (kinetics) of papaya and kiwi in sucrose and glucose solutions.

The constancy of osmotically processed cherry studied by Torregianni et al. (1987), to analyze the sugar content, color, acidity, vitamin C, pH and organoleptic distinctiveness. The transfer of mass during OD of pineapple was reported by Beristain et al. (1990). Many research papers or review papers were published (Torregianni, 1993) dealing with a variety of parameters, such OD mechanism and modeling of solid gain and water loss (Rastogi et al., 2002).

**Osmotic dehydration of fruits**

In modern period, osmotic dehydration is an important intermediate step or pretreatment technology which got much attention in the field of preservation of fruit such as reducing the consumption of energy and improved the food products quality. Much of work has been done on the kinetics of solute /exchange of water in and out of food tissues (Giraldo et al., 2003), application of vacuum pulse during osmotic treatments and special effects on impregnation time (Mujica-Paz et al., 2002).

Osmotic dehydration (OD) was most popular method of pretreatment drying for food materials which caused the reduction of energy costs and better the quality of end products (Andres et al., 2007; Ortega- Rivas, 2007). OD was frequently done by immersing the sample in concentrated solutions of salt or sugar. It was to apply in variety of fruits by decreasing the moisture contents up to 30% (Rastogi et al., 2002; Beaudry et al., 2004). The potential of chemical that existed between solution and sample of food which led to transfer mass fluxes, that’s why water come out of the sample and solutes entered in to tissue. Since osmotic pressure was dynamic force for transfer of mass, OD was time consuming and slow process (Dhingra et al., 2008; Pardo and Leiva, 2009). As a result, to change the formulation of food system and enabled for further processing (Torregianni and Bertolo, 2001).

In sucrose solution, the osmotic dehydration of mango subjected by temperature (30–50°C), immersion time (60–150 min) and concentration of solution (40–60% w/w) was studied. The water loss was maximum and incorporation of solid was minimum to get the product similarity with non processed fruit. Removal of water up to 25% with less than 6% solid uptake could be possible if condition was suitable by using sucrose 44% (w/w) solution, temperatures (38°C) and processing time up to 80 min (Azoabell and Francinaide, 2008).

Osmotic dehydration of Andes berry and tamarillo by using of three different osmotic agents: sucrose (70%), sucrose (70%)-glycerol (65%) 1:1 and ethanol. Water activity in fruits was lowered and promoted the constituents of flavor and moving of anthocyanins to somotic solution by using of this practice (Olorio et al., 2007). The loss of water and solid gain was caused by the application of osmotic treatments. The most helpful effect of osmotic dehydration was on lycopene, ascorbic acid and on the color quality. The result of osmotic pretreatment enhanced constancy of frozen product and extended shelf life (Olatidoye et al., 2010).

The pigments, flavor precursors and volatile compounds were transferred from fruit to osmotic solution. It was suggested that osmotic syrups can be effectively applied to natural additives in food and pharmaceutical industry (Morales et al., 2005). Mango slices were applied to osmotic dehydration in different hypertonic solutions of sucrose and glucose at three different temperatures (30, 50 and 60°C) to devoid of agitation (Ngoran Essan Bla Zita et al., 2009).

The mechanical response of mango was studied by using of 45 and 65°Brix as osmotic treatments which consisted of calcium lactate at different concentrations (0%, 1% and 2%), at the start of process, the vacuum pulse was applied. Dehydrated mango samples at 30°Brix were characterized as mechanical properties such as sugar and gain of calcium, loss of water and changes were done during treatments. Through compression test, mechanical properties were measured which effected by treatment conditions. At 2% concentration of osmotic solutions was influenced of calcium on mechanical properties by using 45°Brix of sucrose and vacuum pulse and promoted the calcium and solute gain. The samples
become firmer, shorter and stiffer. Gain of calcium in the tissue particularly explained the mechanical changes but concentration and structural profile which developed in the tissue also promoted to the mechanical pattern (Torres et al., 2006).

The reduction of weight (WL %), loss of water (WR %) and solute (sugar) gain (SG %) were observed in osmotic dehydration of mango slices. The phenomena of mass transfer were affected by temperature and process time. Temperature and process time were different from the range of 40 to 120 minutes and 30 to 50°C respectively (Gabriela et al., 2004). Osmotic dehydration process was done to increase the final quality of product. This pretreatment was done on banana and tomato rings, which helped to study of kinetics of osmotic dehydration, color properties and organoleptic evaluations. The results showed that much reduction of weight when 100% sucrose used as osmotic agent in banana. The tomato showed the highest values when 30% NaCl and sucrose: salt (1:1.5) were used. The osmotic dehydration of tomato showed the lower chroma (C*) and redness values (a*) during osmotic dehydration (Ali et al., 2010).

Mechanism of osmotic dehydration

Osmotic treatment was done on the basis of minimum dehydration for food. The base of osmotic treatment was osmosis, physical phenomena motivated by variation in solute concentration of two regions which separated or divided by semi-permeable membrane, causing the water movement from low solute to higher solute concentration region with the help of membrane. When water consists of cellular tissue was wrapped in solution of hypertonic which low in molecular substances such as salts and sugars. The movement of solutes from solution to material and it dependent on difference of concentration between food material and solution which gave up two simultaneous counter flows and water outflow from material to solution (Shi and Le Maguer, 2003).

It dependent on the nature of nonselective cell membrane, the own soluble constitutes of product such as sugars, organic acids and minerals also traveled to the product along with outward stream of water. That’s why this movement may be quantitatively unimportant to major types of mass transfer; it may be much resemblance with nutritional and sensory attributes of final quality of the product (Raoult-Wack, 1994; Azoubel and Murr, 2002; Sunjka and Raghavan, 2004). Transfer of mass continued till equilibrium osmotic dehydration was achieved. It was recommended that through capillary flow and diffusion, removal of water took place whereas uptake of solute to the product and leaching of the soluble solids of the product were only took place through diffusion (Shi et al., 2009).

During osmotic treatment, food particles consisted of two phase behaviors in term of water and transfer of solutes. The dewatering of food material was well known to take place in high rate require more than few hours. After first several hours the rate of water loss slowly decreased in succeeding hours (6 hours) and finally flattens out. On the other way, solute impregnation into material was insignificant at the start of osmotic treatment, when dewatering rate was become lower then increased the solute rate into the material (Raoult-Wack, 1994). Early work on the osmotic treatment of food material was reported by Ponting et al. (1966), who explained the process as a moderate, non-thermal means of dehydration to generate good quality dehydrated fruit while decreased the original weight of the fruit to 50 % and preserved flavor and color.

On the basis of their pioneering work, osmotic treatment has attracted much attraction as practical processing method for fruits and vegetables. Although osmotic treatment has not much popular in the food of animal origin such as fish and meat. It should be clarified that osmotic behaviors of plant and animal were entirely different in terms of compositions and structures. This review was based only for the osmotic treatment of fruits and vegetables. Collignan et al. (2001) provided the review of literature on osmotic treatment of meat and fish products.

Osmotic dehydration and infusion

There were two major divisions of osmotic treatment of foods such as infusion and osmotic dehydration. Although these two terms can be used interchangeably (Shi et al., 2009) and distinguished in scientific literature (Kuntz, 1995), the application and end-product properties were much different. The main reason of OD was to get maximum water removal from the product while lowering the solute uptake from adjoining osmotic solution.

On the other way, aim of infusion was to get the maximum transfer of external solutes into food with reasonable removal of water and maximum quality of final product (Raoult-Wack, 1994; Kuntz, 1995; Zhao and Xie, 2004). The process of infusion may also be called candying due to higher level of solute impregnation (Raoult-Wack, 1994). Osmotic dehydration completed within the day, whereas infusion took several weeks to complete (Zhao and Xie 2004). The reason was that water removal quickly took place at the start of osmotic process and latter on slowed down, while rate of solute gain increased.

The review of literature explained that most of work has been directed towards OD, and little bit research has been done to find out the ways to increase the solute gain and infusion efficiency. The reason was
that, methods which were used to prepare good the quality of infused or candied fruits being protected by patents (Mochizuki et al., 1971; Kahn and Eapen, 1982; Tucker, 1997). This was most probably because the infusion was a beneficial process in which fruits can be impregnated with reasonably priced solutes (e.g., sugars) to get the substantial increase in product yield and weight (MacGregor, 2005).

In distinction, the literature provided the enormous amount of information on osmotic dehydration. It was usually recognized that osmotic dehydration did not effect to get the microbial stability (Azoubel and Murr, 2002). In addition, Marani et al. (2007) explained that osmotic dehydration could be an effective dewatering step to significantly reduce the energy requirement for freezing of fruits. The main advantage of solid uptake into material which occurred during OD, the valuable compounds and additives can be integrated in order to get better original nutritional and by taking and organoleptic properties of the raw material (Raoult-Wack, 1994; Torreggiani and Bertolo, 2001).

The osmotic dehydration has gained much attention in related to research, while dewatering impregnation soaking has coined to better explain the nature of process (Raoult-Wack, 1994; Torreggiani and Bertolo, 2001). Much research was conducted to investigate solid gain, kinetics of dewatering and developed mathematical model in order to characterize the osmotic behavior of food material. Such model has proposed for carrots tomatoes (Azoubel and Murr, 2004) and mango (Giraldo et al, 2003). These planned models were helpful in predicting transfer of mass phenomena and the control of various intrinsic and extrinsic factors of the process. However, the application of these models was limited due to variation of plants materials and structural responded of material to osmotic solution (Chiralt and Talens, 2005).

**Process parameters of osmotic dehydration**

Transfer of mass during osmotic dehydration inclined by temperature, size and geometry, concentration of osmotic solution, material to solution ratio, agitation, degree of solution, and methods of pre-drying. Temperature was much important factor which involved in breaking the integrity of plant material and membrane; for example plasma membrane started to undergo irreversible damage at 50°C (Thebud and Santarius, 1982). With increasing the level of agitation then was increasing the rate of dehydration. The sufficient level of agitation ensured the minimization of mass transfer affected on liquid side (Rastogi et al., 2002). When the time spent over, then membrane did not provide barrier for the solute, which penetrated to the cell (Mauro et al., 2002).

The product mass ratio and solution was brought on different effects in the solution of dehydrated process. The driving force decreased to release of water when osmotic solutions become dilute. The shape of material was another factor in OD. If the size of solid material was bigger then dehydrate rate would be slowed because the length of diffusion path was higher. So process dependent on the food nature, structure and weight of osmotic solute and pressure was also affected on transfer of mass (Rastogi et al., 2002).

**Different types of osmotic solutions**

The selection of solutions for osmotic treatment of food was of major importance; it provided driving force for concurrent flows of water and solute, then measured the rate and extent of solute uptake and removal of water as well as sensory and physical properties of the end product. It always careful to select the osmotic solutions to get the desire rate for processing and properties of the ending products. The ability of solutes in relations with other components of food was an important criterion for selection (Pan et al., 2003).

The selection of cost for osmotic solution was very important. Although any solute which was dissolved in water can be used, the compounds that were commonly used as osmotic agent including sugars and sodium chloride (Raoult-Wack, 1994). Sugars were used for the osmotic treatment of fruits and sodium chloride had reported osmotic agent for vegetables (Contreras and Smyrl, 1981; Azoubel and Murr, 2004).

But when NaCl was used, the taste of product becomes salty that was not desirable (Leric et al., 1985; Azoubel and Murr, 2004). So sugar has been reported as excellent osmotic agent that provided many benefits that were inhibitors of polyphenoxidase, oxidative browning caused by enzymes in many vegetables and fruits. Sugar had beneficial in the respect of to protect the essential volatile compounds, which was helpful to restore the sensory properties of original food material (Ponting, 1973).

Sugars were further helpful to contribute stability of pigments and excellent retention of volatile compounds during drying of osmotically treated materials (Ferrando and Spiess, 2001). A combination of solutes was used to check the properties of materials. It had been reported that adding the small quantity of sodium chloride to the solution of sugar boosted up the osmotic drying force due to its lower molecular weight and higher capacity of decreasing the water activity (Leric et al., 1985; Taiwo et al., 2003; Azoubel and Murr, 2004).

Kaymak et al. (1996a; 1996b) evaluated that the osmotic treatment of green peas with a sucrose/trisodium citrate solution after air drying (65°C, 10 % RH) improved the drying rate and rehydration quality of final product. They concluded that trisodium citrate helped in diffusion of water. The samples treated with sucrose or trisodium citrate retained the original color with more suitable flavor and texture when compared to non treated samples and those treated with sucrose (Kaymak et al., 1996b).

Molecular weight was another important factor that determined the rate and mass transfer, if
molecular weight of solutes was small (monosaccharides) then it penetrated into food more rapidly than higher molecular weight. The smaller molecular weight was desirable for the process of infusion then end product quality was excellent. On the other way solutes of higher molecular weight were selected carefully for osmotic dehydration to ensure the higher rate of water removal with little uptake of solute (Saurel et al., 1994; Kuntz, 1995). Among different types of solutions, sucrose was ideal as osmotic agents for OD of fruits.

It was recommended that by using of sucrose for OD of mango cut into slices which were helpful for maximum removal of water and gaining of solid uptake (Rincon and William, 2010). Sunjka and Raghavan (2004) reported high fructose corn syrup (HFCS) over sucrose for OD of cranberries as it produced maximum water loss and solid gain as compared to sucrose.

Factors related to Product

On the side of product, maturity, species and variety effected on structure of cell membrane, natural structure of tissues, soluble to protopsectin ratio, insoluble amounts and entrapped air (Lazarides, 2001). The chemical composition (fat, protein, salt and carbohydrate), physical structure (fiber orientation, porosity and skin), may be effected by the kinetics of osmosis in food (Rahman, 2007).

Mainly porosity of the material was affected on transfer of mass rate and phenomena of shrinkage (Mavrourdis et al., 1998a) as well as ratio of rehydration. The size and shape of the produce was affected by the surface area to volume ratio of the material with solution. So solute impregnation was controlled the surface phenomena, solute uptake was favored by high specific surface values (Lerici et al., 1985; Torreggiani, 1993).

Osmotic environment related factors

Environmental conditions played an important role during OD process of removing the water and migration of solutes. Environmental factors which influenced of solute gain and kinetics of the loss of water such as duration of time treatment and temperature. Less effect of temperature on solid gain but with the increased of temperature, water loss also increased (Beristain, 1990; Li and Ramaswamy, 2006a).

During OD of potatoes, by increasing of temperature up to 45°C, then ultimately increase the water loss and solid gain rates, in good deed of high water loss/solid gain ratios (Lazarides, 2001). Increasing the time of osmotic treatment, the mass transfer rates also increased until both solute and water concentration arrived at symmetry levels. OD for short period of time lowered the color loss during air drying of blueberries (Nsonzi and Ramaswamy, 1998).

However OD for longer period of time with sugar solution gave much loss of moisture and high solid gain. OD was improved by agitation around the syrup sample (Lenart and Flink, 1984; Mavroudis et al., 1998b). Generally concentration of osmotic solution, time treatment duration, temperature and level of vacuum were the major factors of osmotic process (Corrêa et al., 2010).

Benefits of osmotic dehydration

There were two important parameters of OD in food industry (1) quality feature of texture, color, flavor, stability of product, nutrients retention during storage and (2) energy competence. OD was discussed in respect of quality in many articles and also discussed in energy point of view

Quality issues

The concentration of OD was an important tool to reduce the water content with little bit damage on the quality of fresh products. This was done with the mild treatment of product at low temperature (30-50°C); so that temperature did not affect the properties of cell membranes, which was necessary to maintain the osmotic phenomenon (Lazaridis, 2001). The plant tissue was continuously immersed in the osmotic medium because oxygen was not exposed so that there was no need of use of antioxidant to protect against enzymatic and oxidative discoloration (Dixon et al., 1976).

The immersion of food in osmotic medium before air drying was helpful for improving the final product quality since acidity of fruit reduced and prevents the oxidative browning (Ponting, 1973). Osmotic treatments before freezing were done to generate different types of fruits that stored for longer periods with the improvement of texture, flavor, and color after thawing (Sormani et al., 1999) and reduced the drip loss on freeze (Lazarides and Mavroudis, 1995).

Energy saving

Different types of OD applications were using in the processing of fruits and vegetables. However OD was not able to produce the product of low moisture content which has longer shelf life and stability. So osmotic dehydration was using with other drying methods such as freeze, vacuum or convective drying step to get the stable product. So that OD and drying methods were used in combination to reduce the cost of production. Water was removed in liquid form without using external energy (Lazaridis, 2001).

Implementation problems of osmotic dehydration

Osmotic treatments for plants or animals material in concentrated solutions determined the factor due to executive of the concentrated salt or sugar solutions. Main problem occurred in managing the dilution rate. Food or solution ratio was controlled by the constant rate of the exchange of water or solution (Dalla Rosa and Giroux, 2001). Different technologies have been involved to control food or solution ratios (Dalla Rosa et al., 1992).
The basic purpose of these technologies involved the spraying of solution on the food material, and then treated solution was collected and reused. Another problem associated to the implementation of osmotic treatment in the industry was the solute loss and particles from food such as acids, proteins, pigments and aromas which leached into solution. Major problem occurred in modification of pH, water activity as well as physical (viscosity) and sensorial (color and flavor) changes during utilization (Dalla Rosa and Giroux, 2001).

When solution was reused, then re-establishment of solute can be controlled. Several techniques had been used to get the objective, including evaporation at high temperature or low temperature under the application of vacuum, addition of solute to save the cost of energy, concentration of membrane and cryoconcentration. Microbial contamination by yeasts, molds, and lactic bacteria was most common during fruit and vegetable processing. Implementation of HACCP and Individualization of critical control points (CCP) methodology for control process become required when the osmotic treatment process was done without any succeeding process set up to get the stability of final product (Singh and Oliveira, 1994; Leistner and Gorris, 1995).

The product market of osmotic dehydration

The objective of osmotic dehydration was depending on the degree of stability. OD products that removed about 30 to 70% of water were ready to use and can be consumed as shakes or snake commodity. Osmodehydrated products can be utilized in bakery, dairy and candy industries. If food looked like fresh then 20 to 30% water can be removed by the process of osmotic dehydration. This process made the food to semi dried, frozen or treated with chemicals. This osmotic dehydrated food was utilized to produce the concentrates of vegetables and fruits. In France, Italy and Europe are the countries that have been used the modern methods for osmotic dehydration but in Asia, the OD of tropical fruits is become famous preservation method of fruits.

Robles-Manzanares et al. (2004) explained the dehydration and drying conditions to get quince (Cydonia oblonga Mill.) to be used as an ingredient in breakfast cereals. Pieces of Quince were dehydrated in the solution of fructose as concentration 45, 55 and 60°Brix at 30, 40 and 50°C. 45 and 55°Brix at 30°C, the high quality effect which were noted on color, vitamin C, water activity, ascorbic acid preservation and texture. García-Martínez (2002) prepared orange and kiwi jam from OD-treated fruits and to get products of high quality than commercially accessible.

Influence of temperature and concentration of osmotic solution

During osmotic treatment, when temperature increased then loss of water and uptake of solid took place (Saurel et al., 1994; Ispir and Toğrul, 2009). In the literature of osmotic treatment, temperature around 50°C had been used for vegetables and fruits due to the subsequent reasons: 1) this reasonable temperature confined the deterioration of flavor, texture, and thermosensible compounds of the materials, 2) enzymatic browning and flavor deterioration of fruits start at temperature of 49°C (Ponting et al., 1966), and 3) this temperature was also efficient to maintain the viscosity of the solution and adequate infusion time without changing the fruit quality.

It was reported that undesirable changes appeared on the blue berries at temperature of more than 50°C (Shi et al., 2009). Rahman and Lamb (1990) reported that temperature above 50°C may not have a positive effect on solute gain during osmotic dehydration of pineapple with a sucrose solution (sample: solution (w/w) = 1:10). They concluded that sucrose were not capable to distribute as simply as water through the cell membrane at high temperature.

It was also reported that positive manipulate of high temperature on solute gain during the mixture of blueberries (sample: solution (w/w) = 1:1). When solution concentration increased it produced a positive effect on the rate of loss of water due to increase of the osmotic gradient. This has constantly reported for vegetables and fruits, when blueberries infused with different types of sugars (Shi et al., 2009).

The solute gain was assembled with high solution concentration had been reported (Ispir and Toğrul, 2009). This has been recognized to the increase of thick solute layer in the region of the product surface, which slowed the removal of water and created a situation which was more desirable for solute uptake (Nsonzi and Ramaswamy, 1998a). When solution of high concentration was used it had adversely effect on physical properties of the product.

Freezing of osmotic dehydrated products

Freezing of fruits was much important in modern society. The frozen fruits could be carried to that market where access of fruits could not be possible (Skrede, 1996). The freezing of fruits consequences in the better effect with relation to shelf life and availability of all over the year, so that different types of changes occurred during the process of freezing (Martinez-Monzo et al., 2002).

As preservation technique for fruits and vegetables, freezing is used to lower the temperature and water activity which linked to cryoconcentration for fruit liquid state during formation of ice crystals. Strawberries contained high freezeable water content, so freezing implied to cellular damage and decreasing the product quality (Martinez-Navarrete et al., 2001). The reduction of water content by dehydration treatments prior to freezing has been reported as a device for fruit cryopreservation, mainly reducing the freezeable water content (Robbers et al., 1997; Chiralt et al., 2001, Martinez-Navarrete et al., 2001).

Freezing is a method in which temperature of food lower down its freezing point. This method is used
to preserve food such as meat, vegetables and fruits. When water was freeze to ice then it prevent the enzymatic, chemical and microbiological activities (Ramasswamy and Marcotte, 2006). So this preservation method may be resulted in the change of quality such textural damage due to formation of ice crystals particularly in fruits case which contained high moisture content (Hung and Thomson, 1989). Water content of fresh fruits during OD process reduced the amount of water which was accessible to freeze (Li and Sun, 2002) and the result was that to decrease the change in the quality of frozen fruits (Tregunno and Goff, 1996). In addition, OD reduced the energy required for the formation of ice crystals, distribution and cost of packaging (Lowithun and Charoenrein, 2009). That’s why OD was applied to upgrade the quality of frozen fruits (Li and Sun, 2002).

Freezing cause damage the cell structure during the formation of ice crystal. When aqueous solution was freeze, then remaining part of unfrozen water was acted as solvent for all solutes. This concentration determined the function of cell. High concentration of electrolytes influenced the ion interactions, which may help to stabilize the state of proteins. Irreversible reactions took place when protein was denatured and unfolded. Further water and ice interacted with hydrophobic surfaces (Wolfe and Bryant, 2001).

Mechanical damage occurred from ice crystals when flexible components of cell were frazzled in areas where ice was present. During frozen storage, crystals went to metamorphic changes because systems move towards the state of equilibrium where free energy was minimized. Size of ice crystals carried on growing and applied extra stresses to the cell membrane (Kobs, 1997).

Repaid freezing was done for the commercial freezing of foods. So that’s why cause of damage took to different forms such as toxicity was caused by effecting of concentration (Hebert et al., 1981) or structural damages within cytoplasm. Cytoplasmic organelles were susceptible to the loss of functionality due irreversible endocytic vesicles (Dowgert and Steponkus, 1984) or lamellar to hexagonal transitions (Wolfe and Bryant, 1992) aggregation of membrane was due to a decline in charge density, and a lessening in free sterol content of membrane lipids (Uemura and Yoshida, 1986; Tregunno and Goff 1996).

Freezing caused rigorous changes in the properties of product and caused a remarkable texture loss due to cryoconcentration phenomena, which supported the denaturation of membrane. Osmotic dehydration as a pre-freezing treatment had been reported to lower the unwanted changes, which helpful in improving the quality of fruits (Conway, 1983; Forni et al., 1990). If foods stored which was not in frozen stage then would continue to deteriorate.

The effect of osmotic treatment on the mango slices followed by freezing and stored at temperature of -18°C during 20 weeks was evaluated. Osmotic treatments lowered down the moisture contents, titratable acidity, vitamin C levels and lightness, while improving the total soluble solids. The samples treated with high concentrations of sucrose showed less change in properties during frozen storage. The less ripe fruit also has showed the lower acid while picking up sugar and has high vitamin C levels than that of mature fruit (Rincon and William, 2010).

In freezing of foods, formation of small and equally distributed ice crystal was much predicted (Khadakar et al., 2004). According to Sahari et al. (2004), these changes should be predisposed by period of storage, reaction of enzymes and microbiological changes. Urbany and Horti (1992) reported that method of freezing affected on pH. A similar result reported by Sahari et al. (2004) that have completed slow freezing of strawberries at -12°C, pH of the fruits was mentioned during storage and highest value of more than 3.4 that induced the anthocyanin damage in the fruits. The texture resemblance of osmodehydrofrozen kiwi fruit was much low and have great similarities for untreated and treated samples, but the texture of frozen apple treated with sucrose solution, high sugar and glucose contents were also increased (Marani et al., 2007).

The decrease of total soluble solids (TSS) in the mango slices after storing of one month. The nutrient loss of frozen mango slices during the freezing and storing of fruits were reported by Broto et al. (2002). During frozen storage of the tomato puree at temperatures ranges from -7°C to -18°C, the activity of lipoxygenase enzyme was still continuing, but it was decreased during four month storage (Calligaris et al., 2002). Lisiewka and Kmiecik (2000) also evaluated that the activities of peroxidase, lipase, and catalase enzymes were still continuing in the frozen slices of tomato fruit stored at -20°C and -30°C. Freezing of food can be improved if food is previously osmodehydrated (Li and Sun, 2002).

A total of 93 % of dehydrofrozen apples were received by a sensory analysis panel in a study conducted by Bungt et al. (2004). Although, all records about the positive effect of OD on frozen materials, Talens et al. (2003) explained the volatile profile of kiwi fruit, OD pre-treatment did not cause a prominent change, if compared with fresh-frozen kiwi. Chiralt et al. (2001) analyzed the mechanical reaction of kiwi, mango and strawberry that has or has not been pretreated by osmotic dehydration. The cryoprotectant effect of the OD treatment was to get for strawberries that become firmer and tougher after freezing.

Dermeson louogloua et al. (2005) indicated that osmotic treatment was a suitable method for the pre-treatment of freezing of watermelon. The effect of osmotic dehydration on cryoprotectant was noted to increase the color, texture, lycopene content and hardness compared with non-treated samples. When sensory analysis was done, the sample treated with high DE maltodextrin and oligofructose received better
acceptance than un-treated samples, both were stored for 180 days. Then it has suggested that osmotic dehydration was excellent method for freezing of fruits with brittle texture such as watermelon.

Freezing was best method to prevent damage of mango slices and thus had longer shelf stability. Mango slices immersed in the liquid nitrogen and checked the frozen properties. The study conducted that dipping the mango slices in liquid nitrogen for 0, 30, 40 and 50 seconds and four levels of storage periods for 0, 1, 2, and 3 months. The result showed that 40 seconds immersion of mango slices gave the better result for storage of 3 months, with pH of 4.9, TSS 14.07°Brix, total acid 0.46%, yellow color with brightness of 56.62, hue 85.09, chroma 39.57 and vitamin C content 27.66 mg/100 g, the product was preferred by the sensory panelists (Mulyawanti et al., 2010).

Some fruits and vegetables were not suitable for conventional method of freezing, due to degradation of texture, changing in color, nutritional losses and cost of energy. If pretreatment of OD was done to improve the poor quality of frozen tissues. The application of osmotic treatment of fresh fruits with substitute of osmotic solutes such as oligofructose and high-DE maltodextrin, at moderate temperature (35°C) caused significant amount of water loss and solid uptake. The non-treated samples suffered from degradation of texture and taste deterioration as compared with treated samples (Dermesonlouoglou and Taoukis, 2006).

Fruits texture was to be damaged by freezing. The reason was that fruits consist of much quantity of water, so ice crystals damaged the cellular structure of fruits. A decrease in moisture content was directly related to the water which available to freezing (Li and Sun, 2002), and if less quantity of water was frozen then it would less damage to fruits (Lazar, 1968). Therefore, a pretreatment was done to lower the water content and help in improving the quality of frozen fruits. Osmotic treatments for agriculture materials in 50% sucrose solution showed drip losses and tissues damage of osmodehydrofrozen products were much lower than that of non-treated samples (Ohnishi and Miyawaki, 2005). Osmotic treatment with sucrose syrup lowered the drip loss and moisture content of frozen pineapples.

Osmotic treatments with different levels of sugars affected the quality of frozen rambutan. The fruit pieces were dipped for 60 minutes before freezing at temperature of -40°C, compared with untreated samples. Then stored at -18°C to check the physical and chemical properties for 3, 60 and 120 days. The treated samples were good in taste, texture and acceptability (Lowithun and Sanguansri, 2009).

Texture quality of fruits and vegetables were improved during dehydration pre-freezing treatment (Huxsoll, 1982) and drip loss and structural collapse was reduced during thawing (Forni et al., 1997). The fruit and vegetable products which are rich in vitamins, dietary fiber and minerals can be improved (Fito et al., 2001).

Freezing gave poor results, especially when frozen tomatoes were used for direct consumpti reported that quality of frozen tomatoes was poor when direct consumed. During freezing process, aqueous portion freeze out and formed ice crystals that breakdown uprightness of the cellular components. The osmotic status loosed the cellular membrane and permeability. The metabolic system was damaged, enzyme system was disrupted and turgor was loosed by cell.

The quality changes related to freezing may be led to break down of texture due to formation of ice crystals. Enzymatic activity changes the color which was induced by freezing process (Pinnavaia et al., 1988). Before freezing, dehydration was applied which removed water from the product in such a way the amount of crystals decreased during freezing. OD was reported as pretreatment for freezing (Giangiacomo et al., 1994; Giannakourou and Taoukis, 2003; Pinnavaia et al., 1988).

Urbanyi and Horti (1989); Biacs and Wissgott (1997), Calligaris et al. (2002) observed that progress loss of color which may be took place in frozen tomato during storage. The similar results obtained by osmodehydrofrozen tomato samples. Color loss in untreated samples was more than treated samples. Initial loss of 56% ascorbic acid was observed in untreated samples evaluated that loss of 71% initial value of vitamin C was observed after 12-months storage at -20°C. Fuchigami et al. (1995) reported that decreased the pectin compounds were observed in the worsened texture of frozen carrots.

**Osmodehydrofreezing**

The combined process of OD and freezing is called osmodehydrofreezing which is used to get better texture properties of fruits and vegetables as well as lessen the structural collapse and drip loss. Giannakourou and Taoukis (2003) studied that change in quality of osmodehydrofrozen of green peas treated with maltitol and trehalose combined with CaCl2 and NaCl and they observed that osmotic treatment lowered the quality changes in term of texture, color and retention of ascorbic acid for frozen samples.

The deprived quality of frozen cucumber can be increased by cryoprotection accomplished by pre-freezing step of OD. OD at mild heat treatment can protect the texture and develop flavor. The osmodehydrofrozen improved firmness during storage period. During sensory evaluation got excellent scores (Efimia et al., 2008).

Osmodehydrofreezing was combined process which improved the tomato quality during storage when compared the product by traditional freezing. Retention of ascorbic acid in tomato samples which was dehydrated with glucose and stored at temperature of -20°C for 1 year as compared to without treated
Two processes involved in osmodehydrofreezing such as transfer of soluble solids and water between the material and osmotic solution and transfer of heat during freezing. Dehydration process was associated with transfer of heat process involved the freezing step. Apple was dehydrated with glucose and sucrose solutions and followed freezing was done in conventional air blast tunnel. A good result obtained by dehydration before freezing (Agnelli et al., 2005).

Dehydration and freezing

Frozen and dehydrated low moisture foods were in the form of amorphous metastable state, which was much sensitive to moisture and temperature. The conversion from liquid to the glassy state was the characteristic by discontinuous in physical properties such as dielectric constant, viscosity, free volume and coefficient of expansion which changed the other properties (White and Cakebread, 1996; Vanchy, 2002).

The chemical reaction occurred in frozen foods was the main determinant parameters which affected the quality of food after frozen storage. Oxidation of vitamin C, breakdown of lipids and protein precipitation were common example which decreased the quality of foods (Kerr et al., 1993). The retention of vitamin C in frozen foods was known to be reliant on storage temperature and showed the presence of glass forming substances (Bork and Skibsted, 1997). The rate improvement in frozen cellular material was outcome of cell membranes being disrupted by change in pH, osmotic pressure and salt concentration, which allowed for enzyme-substrate interaction.

Osmo-freeze drying

There were two steps of freeze drying process (1) freezing the product and (2) dried the product by direct contact of sublimation of ice under low pressure. Freeze dried food after packaging that was stored for longer period of time, maintained the biological, physical, chemical and sensory attributes of the fresh material. In freezing process, pressure beneath the triple point was subjected to frozen material. This technique was used for dried products, which hold high sensitive mechanism. However freezing was slow and luxurious method and commonly used for value added products (Cohen and Yang, 1995) and its application for vegetables and fruits were limited (Hammami and Rene, 1997). In accumulation to time consuming process needed extra energy to run the compressor and refrigeration units which were expensive for commercial use. The processing time required during condensation and freezing process was mainly dependent on water content and nature of fruits and vegetables.

Robbers et al. (1997) performed experiment on kiwi fruit to check the effect of osmotic dehydration during freezing. They carried experiment by dipping kiwi fruits in the sucrose solution (68% w/w) for 3 hours, after that they subjected fruits to air blast freezer with temperature of -30°C. They concluded that freezing started at low temperature in the dehydrated product and reduced the temperature of dehydrated products to -18°C in 20 minutes, which was 20 to 30% quicker as compared to untreated samples, so time required for untreated sample is 23-24 minutes.

Dehydrated foods with low moisture content always induced a low freezing point and less freezing time as far as there was less removed of heat and less water to freeze (Spiazzi et al.,, 1998). They proved that reducing the moisture content may also be reduced refrigeration load during freezing which has important impact on the reducing of energy. Liu et al (2008) concluded that consumption of energy reached 35.7%, for condensed vapor 31.8% and 23.3% was used in vacuum pump of the total energy input. According to their statement about 67% of the total energy input was consumed in major drying process and strengthening of the vapor. Osmotic dehydration process reduced the moisture content has direct impact on freezing and condensation, the energy demand was reduced for whole freeze operation.

Osmotic dehydration and pre-freezing method

Dehydration pre-freeze treatments were helpful tool to lower the loss of cellular structure and chemical action of freezing on fruits (Huxxoll, 1982). Fractional water removal from the fruits before freezing led to depress the freezing and increased the microcrystallization and supercooling. The ratio of ice crystals was low in unfrozen state, with the subsequent reduction of sensory and structural properties. Literature indicated that fractional removal of water before freezing, referred to many fruits species (Torreggiani and Bertolo, 2001).

Industry used much energy to freeze the large quantity of water which present in fresh products. A subsequent reduction in moisture contents also reduced refrigeration load during freezing of fruits (Huxon, 1982; Torreggiani, 1993). The main advantage was to concentrate the fruits before freezing also save the packaging and distribution costs and high quality products would be achieved due to reduction of structural collapse. It had confirmed that osmotic treatment improved the texture properties of thawed vegetables and fruits (Torreggiani, 1995; Talens et al., 2002) lowered the enzymatic browning and reduced
structural collapse and trickle loss during thawing (Forni et al., 1990).

**Conclusion**

Osmotic dehydration (OD) is one of the most important complementary treatment and food preservation technique in the processing of dehydrated foods, since it presents some benefits such as reducing the damage of heat to the flavor, color, inhibiting the browning of enzymes and decrease the energy costs. The main advantages of osmo-dehydrofreezing are not only economical but save energy, packaging and cost of distribution due to importance of product. The dehydrofreezing process also concerned with improving of quality.

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