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Osmotic dehydration of fruits in food industrial: A review

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Abstract

Osmotic dehydration (OD) is an operation used for the partial removal of water from plant tissues by immersion in a hypertonic solution, sugar and/or salt solution, to reduce the moisture content of foods before actual drying process. Research applications of osmotic dehydration to food processing in technology and in component transfer mechanisms are being carried out in several countries. This technique is a partial dehydration process to give the product a quality improvement over the conventional drying process. Osmotic dehydration is affected by several factors such as osmotic agent, solute concentration, temperature, time, size, and shape and tissue compactness of the material, agitation and solution/sample ratio. The osmotic dehydration step can be done before, during or after the conventional drying process to enhance the mass transfer rate or to shorten the duration of drying time the quality of osmotically dehydrated products is better and shrinkage is considerably lower as compared to products from conventional drying processes. This technique helps to conserve the overall energy relative to other drying procedures. In this review, the mechanism of osmotic dehydration is described. In addition, some factors that affect on mass transfer during osmotic dehydration reviewed. The major objective of this paper is to discuss the advantage of osmotic dehydration in terms of energy reduction.

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Introduction

Dehydration of the fruits and vegetables is one of the oldest forms of food preservation techniques known to man. Osmotic dehydration is used for partial removal of water from materials such as fruits and vegetables by immersing in aqueous solutions of high osmotic pressure such as sugar and salts (Pandharipande *et al*, 2012). 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,* 2012., Khan, 2012). In osmotic dehydration, foods are immersed or soaked in a saline or sugar solution. This results in three types of counter mass transfer phenomenon. First, water outflow from the food tissue to the osmotic solution, second, a solute transfer from the osmotic solution to the food tissue, third, a leaching out of the food tissue's own solutes (sugars, organic acids, minerals, vitamins) into the osmotic solution. The third transfer is quantitatively negligible compared with the first two types of transfer, but essential with regard to the composition of the product. Its driving force is the difference in the osmotic pressure of solutions on both sides of the semi-permeable cell membranes. Selective and low-molecular cell sap components such as sugars and organic acids to diffuse into the surrounding solution of higher osmotic pressure. Other cell components, only to a small extent, pass outside of the membrane. The diffusion of water and low-molecular weight substances from the tissue structure during the osmotic dehydration is accompanied by the counter-current diffusion of osmoactive substances. For this reason, osmotic dehydration as opposed to conventional drying is characterized by the complex movement of water, substances dissolved in cell sap and osmo-active substances (Tortoe, 2010) Since the hypertonic solution has higher osmotic pressure with reduced water activity, it serves as a driving force for water withdrawal from the cells solution to the osmo-active solution. The removal of water during osmotic process is mainly by diffusion and capillary flow, whereas solute uptake or leaching is only by diffusion (Rahman, 2007). All these mass exchanges between the osmotic solution and foodstuff may have an effect on the overall yield and quality of the dehydrated product. Complex internal structure and possible damages during processing (Shi, 2008). Hence, such conditions are important in osmotic dehydration processes to allow counter flow of solutes and water. In plants due to semi-permeable nature of plant tissue and low molecular size of water molecules the flux of water coming out of the food is much larger than solute gain from osmo-active substance. This result in a decrease of water content of the product with time till equilibrium condition is established. Therefore, the weight of the foodstuff will decrease, as well the water activity. According to some works, it is reported that up to 50% reduction in the fresh weight of fruits or vegetables can be achieved by osmotic dehydration (Yetenayet and Hosahalli, 2010).

Some researchers have tried to increase the rate of osmotic mass transfer to reduce the processing time (Ispir and Togrul, 2009; Devic *et al*, 2010, Bchir *et al*, 2012, Mundada *et al*, 2011) However, some researches concern to minimize the uptake of osmotic solids, as it can severely alter organoleptic and nutritional characteristics such as the loss vitamin and mineral salt of the products (Shi and Xue, 2009; Jalaee *et al*, 2010, Phisut, 2012). During osmotic dehydration, a high osmotic rate would make the process more efficient and practical. Most previous studies have focused attention on rapid and effective removal of desired amount of water from food materials such as fruits by adjustment some factors or the operation parameter (Aouar *et al*, 2006; Moreira *et al*, 2007; Ispir and Togrul, 2009; Devic *et al*, 2010; Bchir *et al*, 2012; Mundada *et al*, 2011). Some factors have been employed to speed up water transfer such as using a high concentration of osmotic solution, low molecular weight of osmotic agent, high processing temperature, stirring process or some pretreatment techniques. Thus, these factors were important to review. However, another concern in osmotic dehydration is currently to minimize the uptake of osmotic solids, as it can severely alter organoleptic and nutritional characteristics of the product. Numerous studied have attempted to reduce large solute uptake by using edible coating material prior to osmotic dehydration (Khin *et al*, 2007; Garcia *et al*, 2010; Jalaee *et al*, 2010). Hence, the influence of edible coating on mass transfer during osmotic dehydration was also reviewed. The aim of this review is to describe some factors affecting the mass transfer during osmotic dehydration process of fruit. The new osmotically dehydrated products and industrial applications require appropriate manufacturing procedures at the industrial level. Thus, an understanding of factors affecting mass transfer during osmotic dehydration is required for the process optimization (Phisut, 2012).

Factors affecting osmotic dehydration process

Some factors that affect on mass transfer during osmotic dehydration such as types of osmotic agent, concentrations of osmotic agent, processing temperatures, agitation or stirring process, pretreatment methods and edible coating were reviewed.

Temprature of osmotic solution

The most important variable affecting the kinetics of mass transfer during osmotic dehydration is temperature (Tortoe, 2010). During osmotic treatment, when temperature increased then loss of water and uptake of solid took place (Alakali *et al*, 2006, Rafiq Khan, 2012). Beristain *et al.* (1990) stated that increase in temperature of osmotic solution results in increases in water lose, whereas solid gain is less affected by temperature (Tortoe, 2010). 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 thermo sensible compounds of the materials, 2) enzymatic browning and flavor deterioration of fruits start at temperature of 49°C, 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 and Xue, 2009; Rafiq Khan, 2012). Lazarides (1994) reported substantial higher sugar gains (up to ca.55%) compared to room temperature conditions during osmotic dehydration of apples at process temperature between 30 and 50°C. The higher uptake values of treatments above 20°C were probably due to the membrane swelling and plasticizing effect, which improved the cell membrane permeability to sugar molecules. Rahman and Lamb (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 and Xue, 2009; Rafiq Khan, 2012).

Concentration of osmotic agent

During extended osmotic treatment, the increase of solute concentrations results in the increase in water loss and solid gain rates (Phisut, 2012).

Conway *et al.* (Conway *et al*, 1983), and Lenart (Lenart, 1992) reported that increase in osmotic solution concentration resulted in corresponding increases in water loss to equilibrium level and drying rate. Therefore, increased osmotic solution concentrations lead to increased weight reductions. This was attributed to the water activity of the osmotic solution which decreases with the increase in solute concentration in the osmotic solution (Marcotte, 1991; Tortoe, 2010). Falade *et al.* (Falade, 2007) monitored the mass transfer during osmotic dehydration of watermelon slabs. The process was carried out at three different sucrose concentrations (40°Brix, 50°Brix and 60°Brix). Water loss and solid gain increased with the osmotic solution concentration increase. Watermelon slabs immersed into 60oBrix sucrose solution showed higher water loss and solid gain compared to those immersed in 40o Brix and 50oBrix solutions. Ispir and Togrul (Ispir and Togrul, 2009) studied the mass transfer during osmotic dehydration of apricot. Apricot was soaked in different sucrose concentrations (40%, 50%, and 60%). They reported that increase in sucrose concentration resulted in an increase in the osmotic pressure gradients and, hence, higher water loss and solid gain uptake values throughout the osmotic period were obtained. Mundada *et al.* (Mundada, 2011) studied effect of sucrose concentration on mass transfer during osmotic dehydration of pomegranate arils. Osmotic dehydration was done in osmotic solution of sucrose having different concentration (40°Brix, 50°Brix and 60°Brix). The increase in water loss and solid gain was also observed with increase of osmotic solution concentration. Pomegranate arils immersed into 60oBrix sucrose solution showed higher water loss and solid gain compared to those immersed in 40oBrix and 50oBrix osmotic solution. Results suggested that, the increase in solid gain and water loss with the solute concentration is due to the highly different in concentration between the fruit sample and osmotic solution which increased the rate of diffusion of solute and water exchange. Increased solution concentration resulted in the increase in the osmotic pressure gradients and higher water loss (Azoubel and Murr, 2004; Phisut, 2012).

Studies by Saurel *et al.* (Saurel, 1994) showed a dense solute-barrier layer formed at the surface of the food material when the osmotic solution increased. This enhances the dewatering effect and reduced the loss of nutrients during the process. A similar solute-barrier is also formed in the case of osmotic solutions with higher molecular weight solutes even at low concentration. Studies by Lazarides (Lazarides, 1994) on apples in a higher concentration sugar solution (65 vs. 45°Brix) for 3 hours, showed a faster water loss (ca.30% increase) at the same time, however, there was a severe loss from the osmotic solution in terms of a much greater uptake of sugar solids (ca. 80% increase). The authors concluded that short-term osmosis under increased concentration favoured solute uptake resulting in lower water loss and solids gain ratios. Results on the negative effect of osmosis by low concentration sucrose solution on fruits have also been reported by Karathanos *et al.* (Karathanos *et al,* 1995). For example, low concentration sucrose solution causes minimal water loss culminating in lower water loss and solid gain ratios (Tortoe, 2010). Moreover, the increased mass transfer of sugar molecules with increasing concentration is possible due to membrane swelling effect, which might increase the cell membrane permeability. These results indicate that by choosing a higher concentration medium, some benefits in terms of faster water loss could be achieved. Additionally, a much greater gain of solid is observed. However, some works reported that high concentration of osmotic agent may not enhance the solid gain. Giraldo *et al.* (Giraldo *et al,* 2003) studied the mass transfer duringosmotic dehydration of mango. The processes were carried out at 30oC, using 35°Brix, 45°Brix, and 55oBrix and 65°Brix sucrose. They reported that water transfer rate increased when the concentration of sucrose increased up to 45oBrix, whereas, this effect did not appear between 55°Brix and 65°Brix, the rate constant being slightly greater for the treatment at 55°Brix. A case hardening effect could be responsible for the mass transfer reduction at the highest sucrose concentration. When external solution is more concentrated, the external liquid penetration is more limited by viscosity. Additionally, the rigidity of external cell layers increases more quickly due to their faster concentration (case hardening effect) (Phisut, 2012).

Type of osmotic agent

The specific effect of the osmotic solution is of great importance when choosing the solution (Tortoe, 2010). The common solute types used as an osmotic agent are sucrose, glucose, sorbitol, glycerol, glucose syrup, corn syrup and fructo-oligosaccharide. Generally, low molecular weight osmotic agent easier penetrates into the cell of fruit compared to high molecular weight osmotic agent (Phisut, 2012). The solute cost, organoleptic compatibility with the end product and additional preservation action by the solute are factors considered in selecting osmotic agents. Sugar and salt solutions proved to be the best choices based on effectiveness, convenience and flavor (Tortoe, 2010).

Togrul (Ispir and Togrul, 2009) studied the effect of osmotic agent on mass transfer during osmotic dehydration of apricot. Various osmotic agents such as sucrose, glucose, fructose, maltodextrin and sorbitol were used. They reported that the highest and the lowest water loss were obtained by sucrose and sorbitol solutions, respectively. On the other hand, the highest and the lowest solid gain were obtained by maltodextrin and fructose solutions, respectively. Sorbitol is obtained by reduction of glucose changing the aldehyde group to an additional hydroxyl group hence it can be named as sugar alcohol. Molecular weight of sorbitol ($C_6H_{14}O_6$) is smaller than sucrose ($C_{12}H_{22}O_{11}$). Sucrose has α-glucose and fructose, joined by glycosidic bond. Sucrose supplies reverse characteristics compared to sorbitol. This can be explained in two ways. One is molecular weight and shape of sucrose. Another is pore structure of apricot. Although maltodextrin has higher molecular weight than the other, maltodextrin can be absorbed as good as glucose. High solid gain in case of using maltodexrin can be explained with its high absorption characteristic. In addition to supplying low solid gain, fructose supplies high osmotic pressure in fruit by virtue of water bonding capacities. Thus, sucrose and fructose solutions are the best in osmotic dehydration of apricots due to high water loss and low solid gain.

Pattanapa *et al.* (Pattanapa *et al,* 2010) studied the effect of sucrose and glycerol mixtures in the osmotic solution on mass transfer of tic pressure gradient and thereby increased the water loss. Additionally, an increase in solid gmandarin. Peeled mandarin samples were immersed in osmotic solution prepared from various ratios of sucrose solution (60%) to glycerol solution (60%), specifically, 9:1, 8:2, 7:3, 6:4 and 5:5 w/w. It was found that the highest water loss was obtained when the osmotic solution of 5:5 was used. This is because of glycerol having a lower molecular weight than sucrose. Increasing the amount of glycerol increased the osmoain was observed when the sucrose/glycerol ratio was decreased to 5:5. This indicated that a decrease in the molecular size of the solute could enhance the solid gain. In fact, mass transfer of the solute depends on the effective diffusion coefficient that can be affected by the radius of molecules (Phisut, 2012).

The comparison between effects of fructo-oligosaccharide and sucrose as osmotic agents in osmotic dehydration of apple cubes were reported by Matusek *et al.* (Matusek *et al,* 2008) the solid gain in case of fructo-oligosaccharide was less than half of the solid gain in case of sucrose. Regarding to the difference in chemical composition and structure which make the osmotic behavior of fructo-oligosaccharide differs from sucrose. This probably due to fructooligosaccharide had a higher molecular weight than sucrose, resulting in lower rate of diffusion. The molecular weight, ionic state and solubility of the solute in water cause differences in the behavior of the osmotic solute. Further, molecular size of the osmotic solute has a significant effect on the water loss to solids gain ratio. The smaller the solute, the larger the depth and the extent of solute penetration. Osmotic process is also affected by the pH of the osmotic solution. Contreras and Smyrl (Contreras and Smyrl, 1981) found water removal to be maximal at pH 3 for apple rings using corn syrup. At pH 2 the apple rings became very soft, maybe due to hydrolysis and depolymerization of the pectin. However, firmness was maintained at pH values between 3 – 6 (Tortoe, 2010).

Agitation or stirring process during osmotic

To enhance mass transfer, agitation or stirring process can be applied during osmotic dehydration because the use of highly concentrated viscous sugar solutions creates major problems such as floating of food pieces, hindering the contact between food material and the osmotic solution, causing a reduction in the mass transfer rates (Moreira *et al*, 2007; Phisut, 2012). The agitation-induced decrease in the rate of solids gain for longer osmosis periods could be an indirect effect of higher water loss (due to agitation) altering the solute concentration gradient inside the food particle. Since diffusion of solutes into natural tissue is slow, most of the solute accumulates in a thin sub-surface layer (Tortoe, 2010). Some reports mentioned that degree of agitation had a significant effect on water loss. Water loss was higher in turbulent flow region than in the laminar flow region. The effect of agitation was studied by Moreira *et al.* (Moreira *et al,* 2007). They compared the effect of agitation and non-agitation treatments. The agitated samples exhibited greater weight reduction, consequently water loss, than non-agitated product. The agitation or stirring process can promote the turbulent flow, resulting in the increment of liquid diffusion during osmotic dehydration. Turbulent flow can enhance the hydrodynamic flow mechanism during osmotic dehydration (Moreira *et al,* 2007; Shi and Xue, 2009)Therefore, the agitation or stirring process could be a good alternative way to enhance mass transfer, leading to the reduction of the contact time to achieve determined moisture content in the food materials (Phisut, 2012).

Contreras and Smyrl (Contreras, and Smyrl, 1981) and Lenart and Flink (Lenart AFlink, 1984) reported that osmotic dehydration is enhanced by agitation or circulation of the osmotic solution around the sample. Agitation insures a continuous contact of the sample surface with concentrated osmotic solution, securing a large gradient at the product/solution interface. Therefore agitation has a tremendous impact on weight loss, whenever water removal is characterized by large external mass transfer resistance. This is the case when water leaving the particle surface hits a high viscosity, slow moving or immobile medium and accumulates in a progressively diluted contact zone. Raoult-Wack *et al.* [A.L. Raoult-Wack] observed that agitation favours water loss, especially at lower temperatures (< 30°C), where viscosity is high and during the early stages of osmosis. The extent of water loss increased with agitation and reached a certain plateau. On the other hand, the rate of solid gain decreased with agitation. For short process periods agitation has no effect on the solids gain. For longer process period solids gain decreased drastically with agitation. The authors concluded that agitation has no direct impact on solid gain throughout the entire osmotic process, since external transfer of the osmotic solute is not limiting (Tortoe, 2010).

Osmotic solution and food mass ratio

An increase of osmotic solution to sample mass ratio resulted in an increase in both the solid gain and water loss in osmotic dehydration (Ponting *et al.* (Flink and Tortoe, 2010) To avoid significant dilution of the medium and subsequent decrease of the (osmotic) driving force during the process a large ratio (at least 30:1) was used by most workers whereas some investigators used a much lower solution to product ratio (4:1 or 3:1) in order to monitor mass transfer by following changes in the concentration of the sugar solution (Tortoe, 2010).

Geometry of the material

According to Lerici *et al.* (Lerici *et al,* 1985) up to a certain total surface area/half thickness (A/L) ratio, higher specific surface area sample shape (such as rings) gave higher water loss and sugar gain value compared to lower surface area samples (such as slices and stick). Exceeding this A/L limit, however, higher specific surface area samples (such as cubes) favoured sugar gain at the expense of lower water loss resulting in lower weight reduction. The lowest water loss association with the highest A/L ratio was explained as a result of reduced water diffusion due to the high sugar uptake. The geometry of sample pieces affects the behavior of the osmotic concentration due to the variation of the surface area per unit volume (or mass) and diffusion length of water and solutes involved in mass transport (Tortoe, 2010).

Operating pressure

Vacuum treatments intensify the capillary flow and increase water transfer, but have no influence on solute uptake. The total water transfer results from a combination of traditional diffusion and capillary flow and is affected by the porosity or void fraction of the fruit (Fito, 1994; Tortoe, 2010).

Process duration

Lazarides (Lazarides, 1994) reported that within the first hour of osmotic dehydration of apple slices the rate of water loss dropped to about 50% of the initial rate and within 3 h the product has lost 50% of its initial moisture, while it more than doubled its initial total solids, picking up sugar. Thus an efficient way to limit solute uptake and obtain large water loss and solids gain ratios is early interruption of osmosis . The studies by Lenart and Flink (Lenart AFlink, 1984) to determine the conditions defining the equilibrium state between product and osmotic solution show that equilibrium is characterized by an equality of water activity and soluble solids concentration in the product and solution. Whereas equilibrium was approached within 20 h, it was found that mass transport data (except for solids gain) were not significantly changed in the period between 4 and 20 h. A period of 3 to 5 h osmotic process was recorded in most non-equilibrium studies (Biswal, 1991; Hawkes and Flink, 1978). It was observed that the first period of time is the most important one, since the transport phenomena are fast and they have a dramatic impact on further evolution of the osmotic process (Tortoe, 2010).

Benefits of osmotic Dehydration

There are some major advantages of osmotic dehydration process in the food industry : quality aspect (improvement in terms of color, flavor, texture, product stability and retention of nutrients during storage, energy efficiency, packageing and distribution cost reduction, chemical treatment not required, Product stability during storage. The importance of osmotic dehydration in terms of quality aspects extensively discussed in several articles (Yetenayet and Hosahalli, 2010). Although the principle of osmosis as a means of water removal has been available for quite some time, application of osmotic treatments to food can be considered among the new or improved techniques with a potential to substantially improve the quality of dried fruits and vegetables at a substantial saving in energy cost. The process can enhance natural flavour, colour retention and softer textures in fruit products when the correct choice of solutes controlled and equilibrated ratio of water removal and impregnation are maintained thereby avoiding additives such as antioxidants (Tortoe, 2010).

Quality issues

Dehydration of foodstuffs by immersion in osmotic solutions before convective air-drying improves the quality of the final product since it prevents oxidative browning and/or loss of volatile flavouring constituents, reduces the fruit acidity (Yetenayet and Hosahalli, 2010). Osmotic pre-concentration is an effective way to reduce water content with minimal damage on fresh product quality. Because of constant product immersion in the osmotic medium, the plant or animal tissue is not exposed to oxygen; therefore, there is no need to use antioxidants (i.e., sulfur dioxide in case of fruits) for protection against oxidative and enzymatic discoloration (Yetenayet and Hosahalli, 2010). Torreggiani (Torreggiani, 1993) and Raoult-Wack (Raoult-Wack) reviewed the merits of osmotic dehydration for product quality improvement and process efficiency. Heat damage to colour and flavour are minimized, as products are not subject to a high temperature over an extended period of time. Discoloration of the fruit by enzymatic oxidative browning is prevented by the high concentration of sugar surrounding the fruit pieces. The process achieves sweeter products compared with conventionally dried products. Fruits and vegetables osmotically dehydrated become very attractive for direct use due to their chem.- ical composition and physico-chemical properties (Tortoe, 2010). On the other hand, partial dehydration and solute uptake have advantages in preventing structural collapse during subsequent drying processes (Maestrelli *et al,* 2001). Osmotic treatments prior to freezing are used to produce several kinds of fruits that can be stored for long periods of time with good retention of texture, colour and flavour after thawing (Yetenayet and Hosahalli, 2010; Maestrelli *et al,* 2001). And prevent loss of extensive drip loss on freeze/thawing (Yetenayet and Hosahalli, 2010). Lenart and Lewicki (Lenart and Lewicki, 1988). Reported much higher retention of taste and flavour substances in osmo-convection drying as compared with those dried by convection. The use of osmotically dried fruits to make high quality chips is one application area to get good quality vacuum fried product. Because of the high sugar content of the product after osmotic dehydration, vacuum frying is a method to produce high-quality deepfat fried fruit chips both in sensorial and textural quality parameters. The best mango chip in vacuum frying was produced with an osmotic solution concentration of 65% (w/v) and temperature of 40oC, which resulted in the highest water loss to sugar gain and provided a good texture characteristic (Nunes and Moreira, 2009; Yetenayet and Hosahalli, 2010). Water content reduction and sugar gain during osmotic dehydration have been observed to have some cryoprotectant effects on colour and texture in several fruits (Chiralt *et al,* 2001). In addition, it has been proven to be a good method to obtain minimally processed fruits, due to the great sensory similarity between the dehydrated and natural product (Yetenayet and Hosahalli, 2010).

Energy savng

For batch drying, the energy efficiency is therefore given as an average value over a drying time and for continuous drying the energy efficiency is averaged over the range of moisture content, or the dryer length, or volume, depending on dryer configuration. In all cases the drying efficiency and energy demand is associated with drying time, which is highly related with volume of moisture in a material to be removed or the rate at which drying accomplished. According to Kudra (Kudra, 2009). Drying is one of the most energy intensive unit operations in food and non-food products processing industries. This is mainly because of high latent heat of vaporization of water to be removed from a product (Yetenayet, and Hosahalli, 2010). Osmotic dehydration can be conducted at low temperatures and therefore is a less energy intensive process than air or vacuum drying (Tortoe, 2010). However this dehydration step generally does not produce product of low moisture content having long shelf life and stability. To get relatively stable product the technique should complement with other drying methods like; convective, freeze, microwave or vacuum drying steps. Therefore harmonization of osmotic dehydration with these energy demanding drying technologies has a merit in terms of maximizing energy use efficiency and reduction of production cost. In OD a significant amount of water is removed in liquid form (not in vapour form) which demands little or no external energy supply. By reducing the moisture content of a product to certain, extent either using mechanical or OD method, ultimately reduce the energy demand required to remove the moisture (Yetenayet and Hosahalli, 2010). Lenart and Lewicki (Lenart and Lewicki, 1988) observed that energy consumption in osmotic dehydration at 40°C with syrup re-concentration by evaporation was at least two times lower than convection air drying at 70°C. In the frozen food industry, high energy levels are used for freezing due to the large quantity of water present in fresh foods. Torreggiani (Torreggiani, 1993) reviewed the usefulness of partial water removal prior to freezing referring to numerous species of fruits. Most often, convective air drying is used for partial dehydration. However, Forni *et al.* observed that heat modifications affected the colour of some fruits such as kiwifruit, under any form of drying technique. For such fruits, osmotic dehydration, which is effective at room temperature and operates away from oxygen, could replace air drying. The high level of solute in osmotically treated productsdecreases water activity and preserves them, thus energy intensive drying process is avoided. In effect, osmotic dehydration reduces water removal load in a subsequent drying step which otherwise consumes a lot of energy. The resultant osmotic solution can be used in juice or beverage industries as a product, improving process economy, or it may be re-concentrated for further drying (Tortoe, 2010).

Packageing and distribution cost reduction

All types of fruits and vegetables could be made available throughout the year addressing the problem of fruit glut seasons. Additionally, a considerable cost reduction occurs in packaging and distribution of osmotically dehydrated product due to the simple nature (reduction in product weight and volume) of osmotically dehydrated products resulting in easier handling and transportation to market. Biswal *et al.* (Biswal *et al*,1991) stated that osmotic dehydrated fruit and vegetables prior to freezing saves packing and distribution costs.

Chemical treatment not required

Calcium chloride, a firming agent, has been used in attempts to preserve apple slices in can in order to improve texture (Tortoe, 2010) Commercial canning of fresh apple is not practised due to inherent problems associated with the gas volume in apple tissue, difficulty of its removal during exhausting (removal of air and entrapped gases from the can before closing), less drained weight and mushy texture (Sharma *et al,* 1991) However, using osmotically treated apple pieces in the canning process result in firmer texture and improved quality of the product (Sharma *et al,* 1991). This process is known as "osmo-canning". Chemical treatment to reduce enzymatic browning can be avoided by the osmotic process (Tortoe, 2010). There are two effects of sugar in producing high quality product: first, effective inhibition of polyphenoloxidase, the enzyme which catalyses oxidative browning of many cut fruits and vegetables and second, prevention of the loss of volatile flavour compounds during further air or vacuum drying. However if the final product after air-drying contains 10 - 20% moisture, enzymic and non-enzymic browning causes slow deterioration of colour and flavour (Tortoe, 2010).

Product stability during storag

At low water activity (due to low water activity by solute gain and water loss), reduced chemical reaction and the growth of toxin-producing micro-organisms in the food are low. The product obtained by osmotic process is more stable than untreated fruit and vegetables during storage. In the case of canning using high moisture fresh fruit and vegetable, water flow from the product to the syrup brine causes dilution and reduced flavour. This is prevented by using the osmo-canning process to improve product stability (Sharma *et al,* 1991). Similarly the use of osmodehydrofrozen apricot and peach cubes in yoghurt improved consistency and reduced whey separation of yoghurt (Giangiacomo *et al,* 1994).

The product market of osmotic dehydration

OD products that removed about 30 to 70% of water were ready to use and can be consumed as shakes or snake commodity. The objective of osmotic dehydration was depending on the degree of stability. 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 (García-Martínez *et al,* 2002). Prepared orange and kiwi jam from OD-treated fruits and to get products of high quality than commercially accessible. Robles-Manzanares *et al.* (Roble-Manzanares *et al,* 2003). 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 (Rafiq Khan, 2012).

Problems on applications of osmotic dehydration in industries

The problem taking place during osmotic dehydration is a large solute uptake. Solids uptake modifies final product composition (i.e. sugar to acid ratio) and taste. The solids uptake blocks the surface layers of the product, posing an additional resistance to mass transfer and lowering the rates of complementary dehydration (Matuska wt al, 2006). The importance of solid gain with respect to both the rate of water removal and the quality characteristics of the final product has attracted extensive research interest. It has been shown that the damage of plant cells due to pretreatment process results in extensive uptake of solids from the osmotic solution. Besides process temperature, type of osmotic agent and osmotic solution concentration show a central role to solute uptake. Furthermore, coating has been suggested as a means of preventing solid gain (Yetenayet and Hosahalli, 2010).

Product sensory quality

Product saltiness or sweetness may increase during the osmotic process or the acidity decrease, which is not desirable in some cases. This can be avoided by controlling the solute diffusion and optimising the process to improve the sensory properties of the product (Tortoe, 2010).

Osmotic solution managemen

The microbial validation of osmotic dehydration for longtime operation and reuse of the syrup by recycling are important factors for industrial applications . Microbial contamination increases with the number of times that the osmotic solution is re-cycled.The cost of the syrup is a key factor for the success of the process. The resulting osmotic solution management is an industrial challenge. These include solution composition and concentration, recycling, solute addition, re-use and waste disposal. The control of solute composition in recycling for single solute solutions is easier than mixed solute solutions. During the re-cycling process, the dilute solution can be re-concentrated by evaporation or reverse osmosis (Tortoe, 2010).

Process control and design

In adequate information and data arising from past research has precluded more effective design and control of osmotic dehydration by the food industry. Further studies are necessary to get a clear understanding of the variation of equilibrium and rate constants with process variables and characteristics of the food materials. Most of the osmotic studies have been concerned with the quantitative prediction of the processing factors, but more qualitative prediction of the processing is necessary for industrial use in process design and control. On-line measurements of concentration can provide continuous control of the process. Fruit and vegetables tend to float on the osmotic solution due to the higher density of the osmotic solution. Moreover, the viscosity of the osmotic solution exerts considerable mass transfer resistance, causing difficulty in agitation and adherence of the solution to the surface of the food material. However, breakage of the fruit or vegetable pieces may occur by flow of osmotic solution in case of continuous flow process or by mechanical agitation in the case of batch processing. The equilibrium is the end point of osmosis, but for practical purpose a number of other factors should be considered to ensure the quality of the final product. These include damage to the cells and development of off-flavour due to longer processing time and re-use of the osmotic solution (Rahman and Lamb, 1990) Finally, adequate packaging systems are necessary to ensure quality products for consumers (Tortoe, 2010).

Enzymatic browning of fruits and vegetables

Minimally-processed fruits and vegetables form a large proportion of the produce purchased by consumers who are choosing convenient and ready-to-use fruits and vegetables, with a fresh-like quality and containing only natural ingredients. Wound-induced biochemical and physiological changes associated with water loss, respiration and cut-surface browning accompanied by microbial spoilage is the main culprits of deterioration in minimally-processed fruit and vegetables. The extent of browning after processing of a fruit or vegetable is often dependent upon which particular cultivar is used, as shown with apples (Kim *et al,* 1993) and potatoes (Sapers *et al,* 1989). There are about five causes of browning in process and stored fruit and vegetables: enzymatic browning of the phenols, Maillard reaction, ascorbic acid oxidation, caramelization and formation of 'browned' polymers by oxidized lipids. The oxidation of the o-diphenols to oquinones by polyphenoloxidase is the most important cause of the change in colour as the oquinones quickly polymerize and produce brown pigments. There is also a loss in the nutritional value through oxidation of ascorbic acid during enzymatic browning. In the food industry, enzymatic browning can be avoided by using thermal inactivation of polyphenoloxidase instead of blanching and the use of sulphites as anti-browning compounds although the latter has been banned by the USA food and drug administration for most fresh applications. Bisulphites were found to be dangerous to human health, especially in asthmatic patients. The chemical action of the bisulphites is to react with the o-quinones to form colourless complex compounds.A number of natural ingredients and additives are used to control enzymatic browning (Tortoe, 2010).

Mechanism of osmotic dehydration

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 (Rafiq Khan, 2012). Osmotic treatment is actually a combination of dehydration and impregnation processes, which can minimise the negative modifications of fresh food components. It is the partial removal of water by direct contact of a product with a hypertonic medium such as a high concentration of sugar or salt solution for fruit and vegetable. After immersing a water-rich fresh food material in a hypertonic solution, the driving force for water removal is the concentration gradient.

Between the solution and the intracellular fluid. If the membrane is perfectly semipermeable, the solute is unable to transfer through the membrane into the cells. However, it is difficult to obtain a perfect semipermeable membrane in food material because of their complex internal structure and possible damage during processing (Phisut, 2012). 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 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 (Azoubel and Murr, 2002; Sunjka and Raghavan, 2004; Rafiq Khan, 2012). During osmotic processing, two major countercurrent flows take place simultaneously. The first major one is water flow the inside of the samples into the osmotic solution, and the second flow is the osmotic agent diffusion into the opposite.

Direction, which is flowing from solution into the product. This is another flow which is not much considerable, and consists of substances such as vitamins, organic acids, saccharides and mineral salts which flow from food into osmotic solution. Although, this third flow has no considerable amount in the mass exchange, it can influence the final nutritive values and organoleptic properties of food (Khin *et al*, 2005). In general, liquid diffusion occurs in nonporous solids whereas capillary movement occurs in porous solids. The transport of water in liquid solution takes place only by molecular diffusion. In capillary– porous biological materials, mass transfer occurs in gas-filled cavities, capillaries, cell walls as well as extracellular and intracellular spaces. When cellular biological materials are immersed in a high concentration of osmotic solution, osmotic treatment is actually a multicomponent transfer process in which simultaneous, countercurrent solution flows with a combination of dehydration, leaching, and impregnation processes occurring in the biological tissue matrix (Phisut, 2012). 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 (Rafiq Khan, 2012). The mass transfer process of each component in the solid–liquid system is affected by operation parameters and by the presence of other components (Shi and Xue, 2009). When a cellular solid material is immersed in hypertonic solution (sucrose solution), the cells in the first layer of the material contact the hypertonic solution and begin to lose water because of the concentration gradient between the cells and hypertonic solution; then, they begin to shrink. After the cells in the first layer lose water, a "chemical potential difference of water" between the first layer of cells and second layer of cells is established. Subsequently, the second layer cells begin to pump water to the first layer cells and then shrink. The phenomena of mass transfer and tissue shrinkage are spread from the surface to the center of the material as a function of the operation time. Finally, the cells in the material center lose water and the mass transfer process tends to equilibrate after a long period of solid–liquid contact. The mass transfer and the shrinkage of tissue occur simultaneously during osmotic dehydration process. Thus, for a certain operating time, mass transfer and tissue shrinkage are related to a specific part of the whole material (Shi and Xue, 2009; Phisut, 2012). 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. After food material is immersed in the osmotic solution, water is transported by several mechanisms simultaneously: molecular diffusion, liquid diffusion, vapor diffusion (through gas flow), hydrodynamic flow, capillary transport, surface diffusion, and most frequently a combination of these mechanisms. The transfer processes of food material can be considered as follows: (Shi and Xue, 2009).

1. Water and solutes are transported by diffusion in the osmosis process because of concentration gradients.

2. Water and solutes are transported by capillary flow because of the differences in total system pressure which caused by external pressure, shrinkage, and capillarity.

3. Hydrodynamic flow occurs in pores.

4. Water vapor diffusion occurs within partly filled pore because of the capillary–condensation mechanism.

5. Water diffusion occurs at pore surfaces because of gradients at the surfaces (Phisut, 2012).

Conclusion

Osmotic dehydration provides minimum thermal degradation of nutrients due to low temperature water removal process. It presents some benefits such as reducing the damage of heat to the flavor, color, inhibiting the browning of enzymes and decreases the energy costs. The dehydrfreezing process also concerned with improving of quality. Some factors affecting mass transfer during osmotic dehydration are depending on types of osmotic agent, concentrations of osmotic agent, processing temperatures, agitation or stirring process and pretreatment methods. The use of edible coating. Firstly, low molecular weight osmotic agent tends to easier penetrate into the fruit tissue than high molecular weight osmotic agent. In addition, increased osmotic agent concentrations result in the increment of solid gain and water loss. The increase in the processing temperature facilitates the mass transfer process during osmotic dehydration. Additionally, the agitation process had a significant effect on the increase in water loss during osmotic dehydration.

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