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Reviews on osmotic dehydration of fruits and vegetables

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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. Osmotic dehydration found wide application in the preservation of food-materials since it lowers the water activity of fruits and vegetables. In conventional drying process food material goes under phase change because of high temperature-time combinations. High temperature affects the flavor, colour and textural properties of final product. The osmotic dehydration step can be done before 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.

Keywords: osmotic dehydration, preservation, fruits and vegetables, water activity

Introduction

Natural foods such as fruits and vegetables are among the most important foods of mankind as they are not only nutritive but are also indispensable for maintenance of the health. India is the second largest producer of fruits and vegetables in the world. (Assocham, 2011-12) [46]. The purpose of ancient preservation technique drying is to allow longer periods of storage with minimal packaging, reduce shipping weights, and preserve dehydrated plant products and make them available to consumers during the whole year (Wakchaure *et al*., 2010) [41]. There are a number of studies that have addressed the problems associated with conventional convective drying. Main disadvantages of convective drying are long drying duration, damage to sensory characteristics and nutritional properties of foods and solute migration from interior of the food to the surface causing case hardening (Sharma and Prasad, 2005) [33]. Some important properties of the products have changed such as loss of colour, change of texture, chemical changes affecting flavour and nutrients and shrinkage. The high temperature of the drying process is an important cause for loss of quality. Lowering the process temperature has great potential for improving the quality of dried products (Kumar and Sagar, 2009) [23]. However in such conditions, the operating time and the associated cost become unacceptable. To reduce the operational cost different pre-treatments and new method of low temperature and low energy drying methods are evolved (Bal *et al*. 2010) [5]. The applications of osmosis in food processing as a dehydration process have been primarily motivated by economical factors and the quality improvement of the final product. Several studies have described the behaviour of different foods during osmotic treatment to determine optimal practices. This behaviour changes from one food product to another, according to the composition and the structural organization (Akbarian *et al*., 2014) [3].

Mechanisms of osmotic dehydration

Osmotic dehydration accomplished by placing foods such as fruits and vegetables into concentrated soluble solid solutions having higher osmotic pressure and lower water activity. The difference in the chemical potential of water between the food and the osmotic medium is the driving force for dehydration. Comparing to other conventional methods, osmotic dehydration treatment is a simple procedure which requires no mechanical aid and involves decreased cost of energy. It is easy to perform at room temperature, which ensures the retention of color, texture and nutrients with limited loss of volatile compounds and less oxidative changes (Hasanuzzaman *et al*., 2014) [14].

The process of mass transfer and tissue shrinkage extends from the surface to the center of the material with the passage of operation time. At last, the cells in the center of the material lose water and the mass transfer flux likely to equilibrate after an extended period of liquid-solid contact. The shrinkage of the tissues and mass transfer takes place concurrently during the osmotic dehydration process (Phisut, 2012; Phisut *et al*., 2013; Ahmed *et al*., 2016) [30, 31, 2].

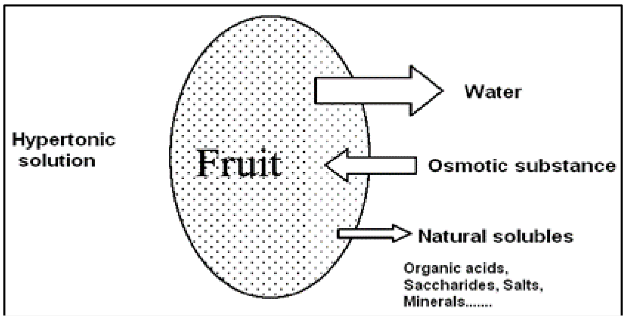

Fig 1: Schematic demonstration of osmotic dehydration process

Advantages of osmotic dehydration

The main advantages of using OD as the reduction of process temperature, sweeter or salty taste of dehydrated product and reduction of 20-30% energy consumption and shorter drying time (Yetenayet and Hosahalli, 2010) [44]. OD improves the nutritional, functional and organoleptic properties of the product and greater sensory resemblance between the dehydrated and natural products (Tortoe, 2010; Ahmed *et al*. 2016) [39, 2]. The left over osmotic solution can also be utilized in beverage industries, thereby enhancing process economy or it may be re-used for further drying (Tortoe, 2010; Agnieszka *et al*., 2016) [39]. Osmo dehydration does not require any sophisticated equipments (Nazaneen *et al*., 2017).

Applications of osmosis process in fruits and vegetables processing

Different kinds of pethas and sweets of parwal made by osmosis in sugar syrup are the best examples of traditional candies. Dried foods, candy, dehydrated vegetables are the main industrial applications of osmotic dehydration. Some researchers already described that osmotic dehydration could be very much beneficial for aonla, banana, jackfruit, sapota, mango, guava, papaya (tooti-fruiti), pineapple, ginger, carrot and also for seafood, meat. They added that the process of osmotic dehydration could be employed in rural areas as entrepreneurs, home scale or with NGO's (Non-Government Organizations) at commercial level since it is economical. The hurdle technology takes advantage of the osmotic dehydration procedure to incorporate the food additive into the product under treatment (Tortoe, 2010; Phisut, 2012; Sutar and Sutar, 2013) [39, 30, 37].

Factors affecting osmotic dehydration process

The selection of process parameters also depends on the application. Choosing the optimal parameters of the process prevents adverse changes that may occur in the case of certain raw materials, especially those with a delicate structure (Ciurzynska *et al*., 2016) [10]. The influence of main process variables (concentration and composition of the osmotic solution, temperature, immersion time, pre-treatment, agitation, nature of the food and its geometry, ratio of solution to sample, among others) on the mass transfer mechanism and product quality has been studied extensively for many products such as for papaya (Jain *et al*., 2011; Garcia *et al*., 2010) [16], banana (Mercali *et al*., 2010, Kumari *et al*., 2012; Verma *et al*. 2014) [24, 40], mango (Welti *et al*., 2014; Oladejo *et al*., 2013) [27], pomegranate (Mundana *et al*. 2011; Bchir *et al*., 2012) [26, 6], ginger (Kejing *et al*., 2013, Patil *et al*., 2015; Jose *et al*., 2016) [21, 17], pumpkin (Ana *et al*., 2013) [4], sapota (Kedarnath *et al*., 2014) [20], coconut (Kamalanathan and Meyyappan, 2015) [15], mushroom (Kaur *et al*., 2014) [19], litchi (Bera and Roy, 2015) [8] and pineapple (Dhingra *et al*., 2014).

Osmotic agent

Osmotic agent or combination of more than one osmotic agents are applicable in osmotic dehydration. Osmotic agent must be effective, convenient, non-toxic and have a good taste. It should be readily dissolved to form a high concentrated solution and not react with the product also price should be low. The common solute types used as an osmotic agent are salt, sugar, jaggery, honey, sucrose, glucose, fructose, sorbitol, glycerol, glucose syrup, corn syrup, maple syrup, starch, fructo-oligosaccharides, maltodextrin and ethanol (Ahmed *et al*., 2016; Brochier *et al*., 2015) [2, 9]. Sugar and salt solutions proved to be the best choices based on effectiveness, convenience and flavor (Tortoe, 2010) [39]. Sugar solution reduces browning by preventing oxygen entrance, provides stability to pigments and helps retain volatile compounds during drying of osmotically treated materials (Pattanapa *et al*., 2010) [29]. The combination of different osmotic agents were more effective than sucrose alone due to combination of properties of solutes (Yadav and Singh, 2014) [43]. Various osmotic agents such as sucrose, glucose, fructose, maltodextrin and sorbitol were used for OD of apricot. Results showed 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 (Ispir and Togrul, 2009) [15]. Brochier *et al.* (2015) [9] studied the effect different types of osmotic agent such as glycerol, maltodextrin, polydextrose and sorbitol on the osmotic dehydration of yacon for diabetics. The best results were reported for glycerol and sorbitol with 80 ± 4% and 81± 1 per cent of water removal with increase of 3.73 ± 0.11 and 4.30 ± 0.16 times in total soluble solids, respectively. Recently, honey has been used to enhance the osmotic dehydration process. Honey sugar consists of fructose, glucose, maltose, sucrose and other carbohydrates. In comparison to single sugar solutions, honey solution has a high osmotic pressure, thereby permits rapid water diffusion. (Zhou and Jiang, 2009) [45]. Application of ethanol as osmotic agent decreases the viscosity and freezing point of osmotic solution in cooling and freezing processes. It lowered the water activity of the product and enhanced the storage stability of the product.

Concentration of osmotic solution

The concentration of osmotic agent plays an important role in osmotic dehydration. Increased solution concentration resulted in the increase in the osmotic pressure gradients and higher water loss (Phisut, 2012) [30]. During extended osmotic treatment, the increase of solute concentrations results in the increase in water loss and solid gain rates (Phisut, 2012) [30]. Less concentrated sucrose solution leads to minimal loss of water and solid gain ratios (Tortoe, 2010) [39]. However, the case hardening influence of high sucrose concentration could reduce the mass flow within fruits and vegetables (Phisut, 2012) [30]. Similarly, Ispir and Toğrul (2009) [15] evaluated the mass transfer rate of apricot during osmotic dehydration. Apricot fruits were immersed in three different sucrose concentrations (40%, 50% and 60%). The higher concentration of sucrose leads to greater osmotic pressure gradients, thereby leading to higher solid gain and water loss throughout the osmotic treatment period. Likewise, Mundada *et al*., (2011) [26] studied the influence of various sucrose concentrations (40°Brix, 50°Brix and 60°Brix) on the mass transfer rate of pomegranate arils during osmotic dehydration. Pomegranate arils soaked in 60°Brix sucrose solution showed higher solid gain and water loss as compared to the samples soaked in 40 °Brix and 50 °Brixs osmotic solution. The concentration and temperature of osmotic solution had a significant role in enhancement of mass transfer in terms of water loss and solid gain (Kaur *et al*., 2014) [19].

Sample to solution ratio

The solution to sample ratio is another important parameter which affects osmosis. The change in ratio affects the mass transfer during osmosis up to a certain limit. Solution to sample ratio should be chosen wisely so that the driving force for the removal of the moisture exists till the end of the process. The driving force decreased to release of water when osmotic solutions become dilute. As the dehydration progresses, the osmotic solution become increasingly dilute and the driving force for further release of water drops (Ramya and Jain, 2016). Most of researchers used the sample to solution ratio ranging from 1:1 to 1:5 in order to study the mass transfer kinetics by following changes in concentration of solution and other factors. An increase of osmotic solution to sample mass ratio resulted in an increase in both the solid gain and water loss in osmotic dehydration (Flink and Tortoe, 2010) [39]. 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) [39]. However, it is essential to use an optimum ratio since large ratios offer practical difficulties in handling the syrup fruit mixture for processing. A ratio of 1:2 or 1:3 is optimum for practical purposes (Tiwari, 2005) [38].

Temperature of osmotic solution

The most important variable affecting the kinetics of mass transfer during osmotic dehydration is temperature due to the increase in cell permeability with respect to process temperature (Tortoe, 2010; Khan, 2012; Bera and Roy, 2015) [39, 22, 8]. On the other hand, temperatures above 45°C can cause undesirable changes in colour, flavour and aroma, as well as changes in the food cell wall. The effect of temperature is more pronounced between 30 to 60°C for fruits and vegetables on the kinetic rate of moisture loss without affecting solid gain. The solid gain is less affected by temperature. Initially, the water loss and solid gain increases as temperature increases upto50◦C depending upon the fruit and variety and later on falls sharply becoming nearly constant at 60◦C which indicated negligible increase in the rate of sucrose diffusion above 60◦C. Since water loss is higher at higher temperature, the osmotic equilibrium is achieved by flow of water from the cell rather than by solid diffusion. Also acceleration of water loss without modification of sugar gain when temperature is increased has been observed by many authors. It was reported that undesirable changes appeared on the blue berries at temperature of more than 50ºC (Shi and Xue, 2009; Khan, 2012) [34, 22].

Duration of osmotic dehydration

The increase in immersion time leads to higher loss of moisture during osmotic dehydration (Ispir and Toğrul, 2009; Mundada *et al*., 2011) [15, 26]. Previous studies indicated that the solid gain and weight loss of the produce during osmosis attain equilibrium state with respect to time (Ispir and Toğrul, 2009; Phisut, 2012) [15, 30]. However, in the initial period of rate of osmosis is very high, and have a significant impact on further progression of the osmotic process (Tortoe, 2010) [39]. In general, as the time of treatment increases, the weight loss increases, but the rate at which it occurs decreases. The treatment time can be selected in such a way that the amount of water removal is maximum with no appreciable uptake of solids.

Effect of agitation

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 (Phisut, 2012) [30]. 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 (Tortoe, 2010; Shi and Xue, 2009) [39, 34]. The agitation has no direct impact on solid gain throughout the entire osmotic process (Tortoe, 2010) [39]. Tiwari (2005) [38] observed that the speed of agitation had a positive effect on water loss during osmotic treatment. Agitation is indeed one of the key factors and an adequate level of agitation ensures minimization or elimination of liquid-side mass transfer effects (Rastogi *et al*., 2002) [32]. The gentle agitation has little effect on osmosis rate at low syrup concentration. Agitation is indeed one of the key factors and an adequate level of agitation ensures minimization or elimination of liquid-side mass transfer resistance and constant driving force (Rastogi *et al*. 2002) [32]. Gupta *et al*. (2012) [13] developed a honey-ginger candy using osmo-convective dehydration. The result indicated that, the increase in water loss and solute gain with immersion time and temperature may be because of agitation imparted during osmotic dehydration process, which reduced the mass transfer resistance between the surface of ginger and honey.

Reuse of osmotic solution

In order to make osmotic dehydration more attractive in economic terms, the osmotic solution needs to be reconcentrated by some means, either by evaporation or by adding fresh osmotic reagent. It can be an efficient complementary processing step to thermal dehydration (if not an alternative) in the overall chain of integrated food processing (Rastogi *et al*., 2002; Tortoe, 2010) [32, 39]. Dalla Rosa and Giroux (2001) [11] stated that the problems of used osmotic solution are related to changes in the properties (pH, viscosity, water activity of solution, sensory properties (mainly flavor and color) and increase in organic contents provides a substrate for microbial growth. The spent solution management depends upon the kind of processed material, type of reconcentration technology, pasteurization parameters, process organization and individual adaptation to the given process (Dalla Rosa and Giroux, 2001) [11]. Marconi *et al*., (2016) [25] studied to determine the technical feasibility of reusing sucrose syrup during the osmotic dehydration of peaches combined with hot air drying. The solution remained after osmotic treatment of fruits has been suggested to be applied for other food preparations such as jams, syrup for fruit canning, mixing with fruit juices, fruity soft drinks, pharmaceutical and food industries as a natural additives and animal feed production.

Economical benefits of osmotic dehydration

During the last three decades a lot of work had been done on osmotic dehydration and found that it is one of the best method for preservation because it does not destroy much nutritional parameters color, flavor and texture etc. Considering the importance of the area and the future potential, the European Commission has funded a project entitled ‘‘Improvement of food quality by application of osmotic treatments in conventional and new processes (FAIR-CT96-1118)’’ under the leadership of Professor W.E.L. Spiess, Federal Research Centre for Nutrition, Karlsruhe, Germany, in which 13 other European countries are partners (Rastogi *et al*., 2002) [32]. The process is quite simple, economical (energy requirement is 2-3 times less as compared to the conventional drying and useful technique for producing safe, stable, nutritious, tasty, economical and concentrated fruit products. The combination of osmotic process with air or vacuum drying was found to be less expensive than freeze-drying (Kaur *et al*., 2014; Nazaneen *et al*., 2017) [19]. Osmotic dehydration process will constitute in the future an important step in many processing operations as this process represents a potential saving in energy and improvement of the overall quality of the food product.

Recent developments in osmotic dehydration

Many researchers have been used several methods and systems during osmotic dehydration to enhance the mass transfer by increasing the osmotic pressure of the hypertonic solution or by applying the additional force to the water and solid transfer. These methods include mechanical agitation (centrifugal force), application of vacuum, (pulsed vacuum), heating (microwave and thermal appliance) and use of ultrasound techniques. Membrane damage in OD can be accomplished by non-thermal pre-treatments like application of ultra-sound, pulsed electric field, vacuum, centrifugal force or gamma-irradiation to the biological material prior to osmotic treatment leads to extensive mass transfer. Xin *et al*. (2013) [42] showed that the use of ultrasound allowed shortening the time of osmotic dehydration of broccoli from 30 to 120 min. Additionally, ultrasound-assisted osmotic dehydration minimized the loss of L-ascorbic acid (retention: 79.7-84.4 per cent compared to 63.4-72.3 per cent in undehydrated frozen broccoli samples) and improved colour retention and firmness during refrigerated storage at –25°C for 6 months. Verma *et al*., (2014) [40] observed that the high pressure pre-treatment of banana slices had enhanced the mass transfer rate during osmotic dehydration.

Challenges of osmotic dehydration technology

The industrial application of the process faces engineering problems related to the movement of large volumes of concentrated sugar solutions and in design of equipment for continuous operations. The use of highly concentrated sugar solutions creates two major problems. The syrup’s viscosity is so great that agitation is necessary to decrease the resistance to the mass transfer on the solution side. The difference in density between the solution (about 1.3 kg/litre) and fruit and vegetables (about 0.8 kg/litre), makes the product float. Another important aspect that has not been investigated is the microbiological safety of the process, which should be studied thoroughly before further industrial development. Sucrose syrups can be recycled a minimum of five times without affecting fruit quality, even when no new syrup is added. For this procedure to become economically feasible, the syrup would need to be reconcentrated and reused. Use of multi-effect evaporators for reconcentration of the syrups is the key factor in making an energy-efficient system for water removal. Excess syrup could be used in concurrent canning operations, packaged as a fruit flavoured syrup. However, whatever the composition of the solution, recycling should take into account the microbiological safety of doing so. Considering the flavour loss that can arise in osmo-dried fruits because of the oxidation of flavour oils, which are probably more retained in greater amounts in the products, proper packaging is essential. This problem, however, may be overcome by incorporating an antioxidant in the osmotic solution or by use of a good packaging material.

Conclusions

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 dehydrofreezing process also concerned with improving of quality. The recent developments in the osmotic dehydration has reduced the time of osmosis and increased the moisture loss with controlled solid gain. This process could be used on small scale for development of self-entrepreneurs and home scale industries. Consumption of such nutritional and valued products could be popularized through exhibition and media.

Suggestions for future work

Special attention is required for equipment design especially to handle fragile food material while having provision for automated operation control and online measurement facilities. Osmotic dehydration can be employed for the juice extracted from osmotically concentrated fruits, where juice is expelled from the fruits that are preconcentrated by osmotic dehydration. This essentially enables the production of juice of very high concentration without heat treatment thereby retaining the nutritional and organoleptic properties inherent to the juice.

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