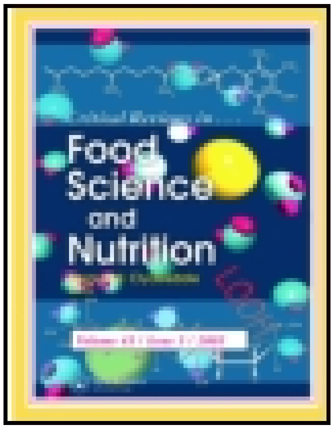

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Recent Development in Osmotic Dehydration of Fruit and Vegetables: A Review

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Recent Development in Osmotic Dehydration of Fruit and Vegetables: A Review

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Abstract

Osmotic dehydration of fruits and vegetables is achieved by placing the solid/semi solid, whole or in pieces, in a hypertonic solution (sugar and/or salt) with a simultaneous counter diffusion of solutes from the osmotic solution into the tissues. Osmotic dehydration is recommended as a processing method to obtain better quality of food products. Partial dehydration allows structural, nutritional, sensory and other functional properties of the raw material to be modified. However, the food industry uptake of osmotic dehydration of foods has not been extensive as expected due to the poor understanding of the counter current flow phenomena associated with it. However, these flows are in a dynamic equilibrium with each other and significantly influence the final product in terms of preservation, nutrition and organoleptic properties. The demand of healthy, natural, nutritious and tasty processed food products continuously increases, not only for finished products, but also for ingredient to be included in complex foods such as ice cream, cereals, dairy, confectionaries and bakery products.

Keyword: heat and mass transfer, osmotic dehydration, solute gain, weight loss

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Introduction

Osmotic dehydration (OD) is a water removal technique, which is applied to horticultural products such as fruits and vegetables to reduce the water content while increasing soluble solid content (Kaymak-Ertekin and Sultanoglu, 2000). The raw material is placed into concentrated solutions of soluble solids having higher osmotic pressure are caused by the water and solute activity gradients across the cell membrane, the cell wall and the surface of the tissue. The complex cellular structure of food acts as a semi-permeable surface. Since these compartments are only partially selective, there is always some solute diffusion into the food. The water transfer is generally accompanied by natural substances (vitamins, flavours, fruit acids, pigments, saccharides and mineral). As consequence of this exchange, the product loses weight and shrinks. OD as a pretreatment to many processes improves nutritional, sensorial and functional properties of food without changing its integrity. It is effective even at ambient temperature, so heat damage to texture, colour and flavour of food is minimized (Rastogi and Raghavarao, 1997). The solute penetration during osmosis first takes place at slow rate but increases with time. Large amount of solute penetration takes place if osmotic dehydration time is long.

OD has been successfully used to reduce water activity of fruits and vegetables to about 0.9, keeping much of original quality. OD is now considered a valuable tool in minimal processing of foods. It can be applied either as an autonomous process or as a processing step in alternative processing schemes leading to a variety of end products (Lazarides *et al.*, 1995). During OD, a product continuously immersed in the osmotic solution, making the process

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oxygen free. There is, therefore, no need to use sulphur dioxide and/or blanching for protection against oxidative and enzymatic discolouration. Also, the process takes place under mild heat treatment (<50^0C) which further colour and flavour retention, resulting in products with superior sensory characteristics (Ponting, 1973). OD is therefore one of the effective ways to reduce overall energy requirements in dehydration and dehydro-freezing processes. OD has been combined with conventional drying methods such as hot air drying to produce shelf-stable fruit products. OD process has been applied to many fruits and vegetables viz. apple, apricot, banana, carrot cherry, citrus fruits, grapes, guava, papaya, mango, potato etc. (Chaudhary *et al*., 1993, Samsher *et al.*, 1998, Singh *et al*., 1998).

Principles of Osmotic dehydration

Osmotic dehydration (OD) is a useful technique for the production of safe, stable, nutritious, tasty, economical and concentrated food obtained by placing the solid food, whole or in sliced in sugar or salt aqueous solutions of high osmotic pressure (Sethi *et al.*, 1999). The principle underlying osmotic dehydration is that water diffuses from dilute solution (Hypotonic solution) to concentrated solution (Hypertonic solution) through a semi-permeable membrane till equilibrium is established. The driving force for water removal is the concentration gradient between the solution and the intracellular fluid. If the membrane is perfectly semi-permeable, solute is unable to diffuse through the membrane into the cells. However, it is difficult to obtain a perfect semi-permeable membrane in food systems due to their complex internal structure and there is always some solid diffusion into the food which means that osmotic dehydration is actually a combination of simultaneous water and solute diffusion process.

Parameters for Osmotic dehydration

The characteristics parameters for osmotic treatment may be determined as: moisture reduction (MR), solute gain (SG) and weight loss (WL) according to the following equations

$$WR = \frac{W_0 - W}{W_0}$$

$$SG = \frac{S - S_0}{S_0}$$

$$WL = WR + SG$$

Where, W_0 = Initial weight of the material (g) at time t = 0, W = Weight of the material (g) at time t; S_0 = Initial weight of dry matter in the material (g) at time t = 0; S = Weight of dry matter (g) at time t,

The volume and bulk density of the food sample can be determined by using Hubbard pycnometer with toluene (20^0C) and the sample shrinkage (V/V_o) calculated according to equation

$$\frac{V}{V_o} = \left(\frac{M_0 - M_t}{M_0}\right)\frac{\rho_0}{\rho_t}$$

V, V_o: Volumes of the sample before and after osmotic treatment, ρ_o, ρ_t: density of the samples before and after osmotic treatment, and M_0, M_t : mass of sample before and after osmotic treatment.

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Chafer *et al*., (2003) evaluated the effect of the osmotic solution (sucrose and dextrose) on the kinetics and process yield of osmotic dehydration of orange. Sugar gain in sucrose solutions was enhanced in comparison with dextrose treatments, whereas diffusional water loss was faster in samples treated with dextrose. These effects made the process yield higher for sucrose solution.

Mass Transfer Kinetics

A method of partial dehydration of fruits by osmosis in sugar or syrup was first described by Ponting *et al.,* (1966). The fruit was reduced to about 50% of its original weight by the osmotic dehydration. Bongirwar and Sreenivasan (1977) conducted studies on osmotic dehydration of banana using sugar syrup of 70% concentration and reported 50% weight reduction by osmosis. There are some conflicting results for apple and papaya (Jackson and Mohammed, 1971; Ponting, 1973; Mehta and Tomar, 1980a). These may be due to varietal differences. However, Chaudhary *et al*., (1993) has successfully applied osmotic dehydration on papaya and reported that weight of the material could be reduced up to 50% by this process. The kinetics of mass transfer in osmotic dehydration is a two-way exchange of solutes and soluble components. The system is schematically described in Fig. 1.

Singh *et al*., (1998) carried out the studies on osmo-air drying of apricot grown in Kumaun Hills of Uttarakhand. The samples were checked in boiling lye (0.2%) solution for 30 seconds, rinsed, soaked in sugar solutions (1:2 ratio) of 30^0, 50^0 and 60^0Bx containing 0.2% KMS for 1 hour, 2 hour, and till the TSS of fruits became constant respectively. During osmosis, mass reduction and sugar penetration values ranged from 28.8-41.5% and 5.48-10.12%, respectively. Bhuvaneswari and Sreenarayanan (1998) conducted the studies on osmotic dehydration of peas. Peas were soaked in osmotic dehydration of sucrose and trisodium citrate at two different concentrations namely sucrose 30%, sucrose 40% + trisoidum citrate 20% at a temperature ranging from 50-70 ^{0}C for duration of 30-120 minutes, both under static and agitated conditions. A sample to solution ratio of 1:4 was used for each experiment and about 40% water loss was observed during osmotic dehydration.

Singh *et al.,* (1998) conducted studies on mass transfer changes during osmotic dehydration of sand pear. The effects of the process variables i.e. sucrose concentration, processing time and temperature, slice thickness, fruit to syrup ratio and agitation of osmotic solution on percent weight reduction and total soluble solids were determined. It was observed that high sucrose concentration and temperature increased the percent weight reduction and total soluble solids. The best results were achieved using 60% sucrose solution at 50 ^{0}C. A thickness of 10 mm with fruit to syrup ratio of 1:4 was found to be suitable. Arora and Kumar (1998) conducted studies on osmotic dehydration of grapes. It was found that total soluble solids increased (4.71-7.17^{0}Bx) when grapes were dipped in hot sugar syrup at 45 and 65^{0}C as compared to those kept at room temperature (2.67 ^{0}Bx). Likewise, moisture removal during osmotic dehydration was more (7.75 - 7.97%) at higher temperature as compared to those at room temperature (6.41%). Thangavel *et al.*, (1998) conducted studies on osmotic dehydration of red banana. Slices of 5 mm thickness were soaked in 63 ^{0}Bx sugar syrup. They observed that when the sugar syrup was maintained at 75 ^{0}C, 50% of water was removed from the slices within 1 hour of osmosis and a maximum of 57.9% of water loss was obtained when the slices were soaked for 2.5 hours.

Chandra and Kumari (2011) studied on the effect of sample to sugar syrup ratio on osmotic dehydrated banana slices. Osmotic dehydration was conducted at the sugar syrup concentrations of 40, 50, and 60^0Brix, sample to sugar syrup ratio of 1:2, 1:4 and 1:6; thickness of banana slice of 8.0 mm; and osmotic temperature of 30^0C. The partially osmotic dehydrated samples were further subjected hot air for final drying at the temperature of 60^0C. The study revealed that the percent moisture loss, weight loss and solid gain increased with increase in sugar syrup concentration from 40-60^0Brix while decrease with sample to sugar syrup ratio and then increased. Drying rate increased with increase in sugar syrup concentrations, slice thickness and sample to sugar syrup ratio. Moisture content decreased more rapidly during initial stage of drying as compared to later part of drying in both drying conditions.

Samsher *et al*., (1998) reported studies on osmo-tray drying of ripe mango slices. The slices were soaked in an osmotic solution of 67.4^0Bx, having sample to solution ratio of 1:3.34. The osmotic dehydration was carried out at an osmotic temperature of 40^0C. The results showed significant amount of weight loss (47.40%) within 4 hours of osmosis. Kumar and Nath (1998) carried out studies on osmo-air drying of ber to develop Chhuhara like products. The ber sample were given different pre-treatments viz. blanching, NaOH and KMS. The best treated ber samples (1% lye, 99^0C and 4000 ppm KMS) dipped for 12 hours) were kept in a sugar syrup of 30^0Bx containing 4000 ppm KMS and syrup strength raised gradually to 60^0Bx. It was found that significant loss of moisture occurred during a period of 7 days.

Advantage and Disadvantage of OD

The advantages of osmotic dehydration as reported by Ponting *et al*., (1966); Huxoll (1982), Islam and Flink, (1982); Biswal *et al.*, (1991); Sharma *et al*., (1991) and Rahman (1992) are as under:

i. Quality improvement in terms of colour, flavour or aroma and texture.
ii. Energy efficient as compared to other dehydration techniques namely air, vacuum and tray drying as it can be conducted at low or ambient temperatures.
iii. Reduction in packaging and distribution costs.
iv. Reduces enzymatic browning.
v. More product stability during storage due to low water activity by solute gain and water loss.
vi. Flavour retention is also more when sugar or sugar syrup is used as an osmotic agent.
vii. There is minimum loss of colour, flavour and nutrient as it is low temperature process.

In spite of the above advantages, osmotic dehydration process has some disadvantages also as reported by Ponting *et al*., (1966), Jakson and Mohammed (1971). The main disadvantage of the osmotic process is that it may increase the saltiness or sweetness or decrease the acidity of the product thus reduces the characteristic taste of some products. This can be avoided by controlling the solute diffusion and optimizing the process from the sensory assessment of the product.

Factors affecting the osmotic dehydration

Type of osmotic agent: The most commonly used osmotic agents are sucrose for fruits and sodium chloride for vegetables. Other osmotic agents include glucose, fructose, lactose, dextrose, maltose, polysaccharides, maltodextrin, corn starch syrup etc. The osmotic agent used must be harmless and have a good taste. Bolin *et al*., (1983) observed the higher diffusivity of HFCS (High fructose corn syrup) compared to sucrose during osmotic dehydration of apples. Lower molecular mass saccharides (glucose, fructose, sorbital etc) favour the sugar uptake because of the high velocity of penetration of the molecule so that solid enrichment instead of dehydration is the main effect of the process. The water activity (a_w) lowering capacity increased as the dextrose equivalent value increased. Logarithmic relationships were found between molecular weight and dextrose equivalent (Argaiz *et al*., 1995). However, diffusion co-efficient decreased with increasing solid contents (Welti *et al*., 1995). Saurel *et al.,* (1994a) found that this was closely related with the formation of a barrier layer, which was promoted by high molecular weight solutes which prevents loss of natural fruit solutes.

Further studies by the same workers on spatial distribution analysis revealed large differences between osmosis distribution curves for the dehydration taking place in sucrose or salt solutions (Lenart and Flink, 1984b). The analysis showed that sucrose accumulated in the thin sub-surface layer resulting in surface tissue compacting (an extra mass transport barrier), salt was found to penetrate the osmosed tissue to a much greater depth. The presence of salt in the osmotic solution can hinder the formation of the compacted surface layer, allowing higher rates of water lose and solid gain. Finally, increasing salt concentration leads to a lower water activity solution with respectively increased driving (osmotic) force. In addition to fruits and vegetables, sugar and salt solutions have also been used successfully for dehydration of animal products.

Collignan and Raoult-Wack (1992) working on fish and meat used concentrated sucrose and salt solutions to partially dewater meat and fish at low temperature (10°C). They observed that the presence of sugar promotes water loss and hinders salt uptake, an important factor in the meat and fish processing industry, since it leads to shorter processing times and better control of salt uptake. Extensive solids uptake is the major drawback against using sucrose, salt or mixed sucrose and salt solutions due to the above-mentioned negative impact on both product quality (nutritional and organoleptic) and on the rate of water removal.

Concentration of osmotic solution: The kind of sugar and its concentration as osmotic substance strongly affect the kinetics of water removal, the solid gain and the equilibrium water content. As studied by Ponting *et al.*, 1966); Contreras and Smyrl (1981); Islam and Flink (1982); Videv *et al*., (1990); Heng *et al*., (1990); Biswal *et al*., (1991) and Sharma *et al*., (1991) that by increasing the molar mass of solute, weight loss and dehydration aspects of the process are favoured and both equilibrium and drying rate increases with the increase of osmotic syrup concentration.

Temperature of osmotic solution: The rate of osmosis is markedly affected by temperature. This is the most important parameter affecting the kinetics. The temperature of osmotic process has been extensively studied by many researchers (Contreras and Smyrl, 1981; Conway *et al.*, 1983; Videv *et al*., 1990; Heng *et al*., 1990; Palou *et al*., 1993 and Samsher *et al*., 1998). The water loss increases with the increase of temperature, whereas solid gain is less affected by temperature. The rate of osmosis increases the mass exchange and diffusion co-efficient but above 50^0C, enzymatic browning and flavour deterioration takes place (Videv *et al*., 1990). The ascorbic acid and chlorophyll retention are also markedly affected. High temperature over 60^0C modifies the tissue characteristics, favouring impregnation phenomenon and thus solid gain (Farkas and Lazar, 1969; Bongirwar and Sreenivasan, 1977; Lenart and Flink, 1984a). Initially the water loss and solid gain increases in temperature upto50^{0}C depending upon the fruit and variety and later on falls sharply becoming nearly constant at 60^{0}C which indicated negligible increase in the rate of sucrose diffusion above 60^{0}C (Rahman and Lamb, 1990). 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 (Ponting *et al.*, 1966; Bongirwar and Sreenivasan, 1977; Hawks and Flink, 1978; Islam and Flink, 1982).

Properties of solute used in osmosis: Islam and Flink (1982) studied the effect of solute type in osmosis. Different osmosis behaviour was observed in sucrose, NaCl and KCl solutes. For sucrose, water loss increased with the increase of sucrose concentration while solid gain was roughly constant with sucrose concentration. On the other hand, both water loss and solid gain increased with the increase of NaCl concentration. KCl also showed a similar pattern as NaCl. These differences between sugar and salts arose from the differences in molecular size, ionic state and solubility of solute in water. Sugar being larger, can not easily diffuse through the cell membrane and thus equilibrium is achieved primarily by flow of water from the cell.

Raoult-Wack *et al*., (1991) studied the effect of molecular weight on water loss and solid gain from agar gel and found that water loss increased from 50 to 85% and solid gain decreased from 50 to 0.5% in 3 hrs of osmosis when molecular weight of solute increased from 87 to 20000 dalton. Moy *et al.,* (1978) investigated the effect of combining organic acids (acetic, lactic and citric acids) and sucrose on the osmotic concentration of papaya and mango and found that acidification increased the rate of water removal. The increment was due to the changed tissue properties (reversal of pectin gelation) and not from the increase in solute concentration, since acids were added at concentrations (1 to 4%) which was low in comparison to the sucrose concentration (60%).

Contreras and Smyrl (1981) found that water removal was maximum at 3.0 pH for apple rings using corn syrup. In more acidic solution (pH 2.0) the apple ring became very soft, where as firmness was maintained at pH values of 3.0 to 6.0. The fact that the apple tissue softens under conditions of low pH and high temperature was probably attributable to hydrolysis and depolymerization of the pectin.

Agitation of osmotic solution: Osmotic dehydration increases when the syrup is agitated or circulated around the sample. This is due to reduced mass transfer resistance at the surface. 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. Lenart and Lewicki (1987) showed that solute penetration during osmotic dehydration in sucrose solution was only to a depth of about 2 - 3mm. However, Ponting *et al*., (1966) stated that in some cases it might be more beneficial if agitation is not used when consideration is given to equipment needs and the breaking of fruit. Raoult-Wack *et al.*, (1989) 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.

Geometry of the sample: Osmotic concentration behavior will depend on the geometry f sample piece. This is due to the variation of surface area per unit volume or mass and diffusion length of the component involved in mass transport. Contreras and Smyrl (1981) found that mass reduction increased to about 1.3 times when apple slice thickness decreased from 10 mm to 5 mm. Lerici *et al.*, (1985) found that solid gain increased as the ratio of the surface area to diffusion length (A/L) increased while water loss increased to a maximum (depending on shape) and then decreased. The low water loss corresponding to higher A/L value was probably due to a reduction of diffusion caused by high solid gain.

Osmotic solution and food mass ratio: Both solid gain and water loss increased with the increase of syrup and food mass ratio up to a certain level and then falls off (Rahman and Lamb, 1990; Palou *et al*., 1993). Ponting *et al.*, (1966) and Flink (1979) reported that an increase of osmotic solution to sample mass ratio resulted in an increase in both the solid gain and water loss in osmotic dehydration. 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 (Conway *et al*., 1983).

Physical and chemical properties of food materials: The chemical composition (Protein, carbohydrate, fat, salt etc.) and physical structure (porosity, arrangement of the cell, fibre orientation and skin) may also affect the osmotic kinetics in food. A remarkable reduction of salt diffusion in fish with and without skin was observed as skin acts as a membrane. Protein also affects the salt penetration in fish. Islam and Flink (1982) observed reduced water loss and increased solid gain when 4 min. Steam blanching per-step used before osmosis. The loss of membrane integrity due to heating is another cause of poor osmotic behavior.

Time of treatment: The loss in water content and gain in soluble solids content is a function of time. In general, as the time of treatment increases, the weight loss increased but the rate at which this occur decreases. Maximum water loss (50% reduction) takes place within the first 2-3 hours depending upon the type of fruits (Ponting *et al.,* 1966; Farkas and Lazar, 1969; Hawkes and Flink, 1978; Bongirwar and Sreenivasan, 1977).

Applications of osmotic dehydration process

Osmotic Dehydration is mainly related to the improvement of nutritional, organoleptic and functional properties of the product. As OD is effective at ambient temperatures, heat damage to colour and flavour is minimized and high concentration of the sugar surrounding fruit and vegetable pieces prevent discolouration. Further more, through the selective enrichment in soluble solids and reduced acidity with little or no use of SO_2, high quality fruits and vegetables are obtained with functional properties compatible with different food systems. These effects are obtained with a reduced energy input over traditional drying process (Torreggiani, 1993). The product thus obtained is an intermediate moisture food (IMF) having moisture content ranging from 65-75% and water activity (a_w) in the range of 0.94-0.97 (Le Maguer, 1988). The commercial applications of OD process for tropical fruits such as banana, mango, apple, papaya sapota and strawberry has been critically reported by Bongirwar and Sreenivasan (1977).

Recently, Sharma (1996) has reported that Osmo-vac dried apple rings after reconstitution in 15^0Brix sugar syrup were better than canned products. Osmotic Dehydration can also be used instead of air drying in obtaining dehyro-frozen foods. The use of OD for partial concentration of fruits and vegetables reduces the moisture content of the material thereby reducing the refrigeration load during freezing, saving packaging and distribution costs and achieving higher product quality because of the marked reduction in structural collapse and dripping loss while thawing (Hoxoll, 1982; Biswal *et al*., 1991)

Combination of osmotic process with other dehydration processes

It has been reported that osmotic dehydration process could be combined with other dehydration processes viz air, vacuum, freeze, tray/cabinet etc. for complete moisture removal so as to obtain stable products. Air drying following osmotic dehydration is commonly used for the production of so called semi-candied dried fruits. The combination has been successfully evaluated by many researchers. The combination of OD with solar drying has been proposed by Islam and Flink (1982). Drying may also involve air drying, vacuum drying, tray drying and freeze drying. Osmotic dehydration coupled with vacuum drying yields puffy products with a crisp, honey comb like structure at an economical cost. The parameter of capillary flow, which is closely related to the fruit porosity, gets intensified by vacuum treatment and plays and important role in water transfer (Xian and Maupoey, 1994). Commercial feasibility of the process has been studied based on semi-pilot scale operations in bananas (Bongirwar and Sreenivasan, 1997). Osmo-vac dried bananas retained more puffiness and a crispier texture than simple vacuum dried ones and the flavour lasted longer (1 year instead of 2 months) at ambient temperature. The natural flavour is retained even better than in freeze drying and colour remains brighter with reduced SO_2 treatment in osmo-vac drying than in vacuum drying. Osmo-vac apple rings packed in laminated pouches were organoleptically and nutritionally better than conventionally dried apple rings (Sharma, 1996). Using high temperature fluidized bed (HTFB) dehydration of osmotically dehydrated blue barriers, fruits with a soft and raisin like texture were obtained by Kim and Toledo (1987). Thangavel *et al.,* (1998) found that osmo-vac dried banana slices could be stored in polyethylene bags (350 gauge) for 30 day without any spoilage. They also revealed that this technique could be utilized for the production of superior quality banana slices suitable for long term storage and export.

Singh *et al.,* (1998) conducted studies on osmo-air drying of apricot grown in Kumauon Hill of Uttrakhand. The osmotically dehydrated fruits were dried in a cabinet dryer at 55 ± 2^0C to a moisture content of 20±2%. It was found that residual carotene contents ranged from 16.9 - 33.9% as compared to control samples (12%). The dried products were also evaluated for sensory tests and it was found that osmotically try dried samples scored maximum in sensory evaluation. According to Bhuvaneshwari and Sreenarayanan (1998), the osmo-air dried peas (dried at 65^0C) showed better dehydration, biochemical and organoleptic qualities. Singh et al (1998) found that, the subsequent cabinet air drying of the osmosed product gave a shelf stable product with improved colour, flavour, texture and overall acceptability over the conventional dried products.

Samsher *et al.*, (1998) reported osmo-tray drying of mango slices at a tray drying temperature of 45, 50, 55 and 60^0C respectively. It was found that organoleptic/sensory attributes namely colour, texture, flavour and taste of mango slices dried at 50^0C were found to be better as compared to those of other temperatures. Kumar and Nath (1998) conducted studies on osmo-air drying of bers to develop 'Chhuhara' like products. The osmotically dehydrated samples were dried in a cabinet air drier at 52 ±2^{0}C for 24 hours. It was found that ber's rehydration ratio was 0.35, residual and free SO_2 in sample after cabinet drying was 1103 and 202 ppm respectively which reduced to 764 and 96 ppm after 60 days of storage. It was also found that product had low microbial count. Its overall acceptability score of 4.23/5.00 and other studies showed osmo-air dried products to be a good chhuhara supplement. Energy requirement was found to be 6 units per kg of dried product.

Application of new food processing technologies with OD

Since the rate of mass transfer during osmotic dehydration is generally low, a number of techniques have been attempted to improve it. These techniques include subjecting the food to ultra high hydrostatic pressure (Rastogi and Niranjan, 1998), high intensity electrical field pulses (Rastogi *et al.*, 1999) or gamma irradiation (Rastogi, 2004; Rastogi and Raghavarao, 2004c) prior to osmotic dehydration and applying ultrasound (Simal *et al*., 1998), partial vacuum (Fito, 1994; Rastogi and Raghavarao, 1996) or centrifugal force (Azuara *et al.*, 1996) during or prior to osmotic treatment. Chou *et al.* (2004) used combination of intermittent Infrared and continuous convection heating to dry various osmotically pretreated potato, carrot (in solutions of 15%, 25% and 35% NaCl) and banana samples (in solutions of 15%, 25% and 35% sucrose).

Chafer *et al.* (2003) was studies by analyzing the effect of blanching pre-treatment and application of vacuum pulse on the kinetics, process yield and product quality (colour and mechanical behavior) of osmotically dehydrated pear cylinders (var. blanquilla). Results revealed that the greatest volume of losses and a reduction of the ratio of sugar gain to water loss, where the highest values reached were for non-blanched samples submitted to vacuum pulse. Bunger *et* *al.*, (2004) were analyzed combined process effects of osmotic dehydration in sucrose solutions and freezing on apple cubes preservation.

Packaging for products developed by OD

Packaging is essential for the safe and easy marketing of any food product and for the retention of their natural characteristics, till consumed or utilized otherwise. As a result of socio-economic changes, packaging has become increasingly important in the scheme of distribution. The use of plastics in food packaging has made tremendous advances in recent years throughout the world, A wide variety of rigid plastics as well as flexible plastic packaging films are used in the forms of carton, bottle, sachet, bag, pouch, box, barrel, tub, collapsible tube etc. by the food industry (Khamrui, 1999). In fact the aim of packaging is to protect the contents during storage, transportation and distribution against damage, which may be physical, chemical or biological. Thus to overcome the losses (which amount up to 25-40% of total fruits) due to improper handling, transportation and storage, the packaging of these perishable commodities is a must. The main functions accompanied by packaging are (Karel et al., 1975b):

i) Packaging serves as a material handling tool containing the desired amount of food within a single container and may facilitate the assembly of several such units in to aggregates.

ii) Packaging may also serve as a processing aid.

iii) Packaging acts as a good barrier against microbial invasion to reduce spoilage and decay.

iv) Prevents the ingress of gases and vapours.

v) Prevents the mechanical damage of the product.

vi) Acts as a means of temperature control.

vii) Packaging serves as a means of literature and gives the detailed information about the proper use of the product.

The packaging of fruits has been in practice many years back. Baskets made up of bamboo cushioned with paddy straw are generally preferred for banana and mango due to their low cost. Other types of packaging materials used are fiberboard boxes, and corrugated card board cartons of different dimensions depending upon the quality and variety of fruit to be packed. Other types of cushioning materials used in addition to paddy straw and wood wool, vinylite and pilofilm wrappers, paper cuttings and news print, tissue paper and polyethylene films (Ranganna, 1994).

Presently the materials which are used in food packaging include metal, glass, paper and paper board, plastics and minor amounts of wood and cotton fibre. However, in category many types of packaging materials or combinations of materials are available. There are dozens of types of polypropylene film with varying moisture permeability, gas permeability, flexibility, stretch, burst strength and so on. Further a new food product requires its own special package since optimum protection, economic considerations, and merchandising requirements change rapidly with variation in product composition, weight and form, and performance demands (Karel et al., 1975b).

A great amount of research has been carried out during the last 20 years with the aim to create modified atmosphere (MA) conditions in food packages by means of controlling the permeability characteristics of the film (Ranganna, 1994). MA packages are dynamic systems where respiration and permeation are occurring simultaneously. Packaging forms the most difficult part of manufacturing ready-to-use and ready-to-eat fruits and vegetables of good quality and prolonged shelf-life. None of the packaging materials available in the market are permeable enough (Day, 1994). Optimal oxygen and carbon dioxide atmosphere cannot be maintained by use of most of the films, especially when the produce has a very high level of respiration. Also research is going on to overcome the shadow casted by the non-biodegradable nature of plastics. For this purpose, and eco-friendly alternative to the plastics called as edible packaging (EP) has been discovered. An edible film or coating is simply defined as a thin continuous layer of edible material formed on, placed on, or between the foods or food components (Torres, 1994). Edible packaging refers to the use of edible films, coatings, pouches, bags and other containers as a means of ensuring the safe delivery of the food product to the consumer in a sound condition. Many researchers have used glass bottles/jars, LDPE, HDPE pouches, and PVC jars for storage of dehydrated fruits and vegetables (Ahmad, 1997; Samsher *et al*., 1998).

Glass jars/bottles: As a food packaging material, glass is chemically inert and an absolute barrier to the permeation of O_2 and water vapour. Physically, glass is a super cooled liquid of vary high viscosity. The principle limitations of glass are its susceptibility to breakage, which may be from internal pressure, impact, or thermal shock, its weight which increases shipping cost and the large amount of energy required for forming into containers (Karel et al., 1975b). Glass is primarily formed from oxides of metals such as silicon dioxide. Food processing in glass bottles has been successfully conducted by many canners in some of the developed countries. In most of these countries, about 40 percent of processed foods are packed in glass containers as against 50 percent in cans and 10 percent in plastic containers. About one third of the total production of glass is used for beverages and other foods. Foods for processing are packed in heat sterilizable light weight glass jars which are 20 to 40 percent lighter than ordinary glass bottles and are more durable. Hermetic lug caps are used in glass containers used for packaging of processed and semi processed food products (Mahadeviah, 1999). For packaging of baby food in glass containers, "Press-on, Twist-off" cap has been developed and then extended for a number of heat processed food products. A few food processing units in India have introduced glass containers for packaging of export oriented vegetables including mushroom.

The major technological developments in glass containers are the reduction in weight, increase in strength and varied shapes. The combination of a light weight glass bottle and preprinted shrink sleeve in vinyl polychrome or in expanded polystyrene is the further potential of glass container for food packaging. Glass containers possessing the proper type of closure can be used practically for all types of packaging applications, including heat processing, gas packaging and other types of preservations requiring hermetically closed containers, (Karel *et al.*, 1975b).

Plastic Film Packaging: As already pointed out that the use of plastics in food packaging has made tremendous advances in recent years throughout the world. A wide variety of rigid plastics as well as flexible plastic packaging films are used in the form of cartons, bottle, sachet, bag, pouch, box barrel, tub, collapsible tube etc. by the food industry (Khamuri, 1999). In fact, the use of plastic films such as low and high density polypropylene, low and high density polyethylene, polyvinyl chloride (PVC), polyvinyleden chloride (PVDC), polystyrene, polyester, polyamide (nylon), saran, cellophane etc. are such wide spread as packaging materials that these have become synonymous with packaging. The use of above plastics as packaging materials, for fruits and fruit products have also been reported by many researchers. The use of many simple and low cost techniques such as wax coating and plastic film wrapping has also been investigated by researchers. Presently, a more useful technique of sealing individual fruit in semi-permeable polymeric films to create a modified atmosphere around the individual fruits has been found more effective at reducing water loss without resulting in an undesirable modification of O_2, CO_2 and C_2H_4 concentrations which may cause injury to the commodity (Kader *et al*., 1989).

Flexible packaging materials made up of laminates consisting of polyamide (Nylon). Polypropylene and polyester/aluminium foil/cast polypropylene have been developed as reportable pouches as an alternative to metal and glass containers for packaging of thermally processed food products. Aseptic packaging materials for unit packs and bulk packaging have been developed for packaging of ready to serve fruit beverages and fruit pulps/concentrates respectively. The materials used for unit packs are made of (i) polyethylene/paper board/PE (tetra-pack), (ii) PE/foil/PE, (iii) Met. PET/PE (iv) composite cans (Paper/foil/PE). For bulk packaging, bag-in-box and bag-in-drum are made of Met. PET/foil/PE. For packaging of frozen foods, widely used materials are waxed paper board containers rigid aluminium foil containers are used for frozen or cooked food containing liquid juice, which need heating before being consumed. Laminates of polyethylene, nylon, saran, polyester, moisture proof cellulose film and aluminium foil are used as shrink or stretch wraps. Boil-in-bag packages made of polyester or nylon laminated to HDPE or PP or PVDC have been adapted for thaw-in-bag for fruits in syrup (Mahadeviah, 1999).

The reasons for indiscriminate adoption of plastics as the main packaging material by the food industry are: (a) they are cheaper, (b) easy to fabricate, (c) can be easily applied and the packaging process can be easily mechanised, (d) loss of moisture from the food is nil, (e) it protects the food from attack by microorganism, insects, and rodents, (f) humidity control is not necessary etc. (Khamrui, 1999).

According to the Kader *et al.*, (1989), the beneficial effects of film packaging can include (i) creation of MA conditions (ii) maintenance of high RH and reduction of water loss, (iii) act as excellent barriers to moisture, odour, oxygen and other gases so that they can maintain the desired shelf-life for various products; (iv) resistant to most chemicals, non-toxic in nature and absolutely safe to use even in direct contact with food products; (v) safe in use as they do not break easily and the broken pieces are not harmful as those of glass and metal; (vi) reduction of surface abrasions by avoiding contact between the commodity and the shipping container; (viii) improved sanitation by reducing contamination of the commodity during handling; (viii) do not promote any bacterial growth and can be sterilized by all conventional methods, hence provide wide applications in food (ix) are tamper-proof, break-resistant, corrosion-resistant and lead-proof; (x) facilitation of band identification. However, the limitations of the film packaging are (i) some chemicals do attack particular plastics, (ii) They are not a total barrier to gases and water vapour, although some new barrier plastics have greatly improved oxygen, gas and odour impermeability, (iii) Abrasion resistance is not always adequate, (iv) Condensation of water takes place within film package which results in fungal growth and decay of fruit/ product.

Anzueto and Rizvi (1985) studied the individual seal-packaging of apples at ambient temperature (20^{0}C). Their results indicated that at 21 ^{0}C, packaged apples extended the shelf- life by 3-4 weeks over non packaged apples.   Ben-Yehoshua (1978) reported that the seal packaging of individual citrus fruits (grapefruits, orange, lemons, mandarins and tangerine) and tomato with 10 μm high density poly ethylene (HDPE) film doubled the storage life as compared to control without packaging. By this method the shrinkage of the fruits was practically prevented and physiological loss in weight was reduced fivefold. Further study by Ben-Yehoshua *et al.*, (1982) revealed that seal packaging of lemons considerably reduced the development of blemishes after 3 weeks of storage.

Ahmad (1997) used HDPE bags of 200 gauge for the storage of dehydrated slices of turnip and reddish. Polyester films have been used in vacuum or inert gas packaging of meat. The LDPE films which have O_2 and CO_2 transmission rates have been used for the packaging of fresh fruits and vegetables. The lined or over-wrapped cartons have been used for the packaging of frozen foods. (Ranganna, 1994). Dehydrated vegetables like peas, cabbages, carrots, onions, potatoes with moisture content of 3-6% are packed in tin containers for bulk packaging and in foil laminate pouches for unit packs. Dehydrated mushroom which is hygroscopic and fragile packed in force play foil aluminates pouches for unit packs. Dehydrated mushroom which is hygroscopic and fragile packed in four ply foil laminate pouches which are put in cartons of duplex board. Spray dried egg powder, milk powder; matted milk foods and infant foods with moisture content of 1-2% and ERH of 5-10% are packed in tin and glass containers for bulk packaging and four-ply foil laminate pouches which are put in cartons of duplex board. Spray dried egg powder, milk powder, matted milk foods and infant foods with moisture content of 1-2% and ERH of 5-10% are packed in tin and glass containers for bulk packaging and foil laminates and composite cans for unit packs (Mahadeviah, 1999). Powdered dehydrated products like fruit juice powders, soups, custard powders, etc. require protection against ingress of moisture and oxygen and loss of volatile flavoring and colors. They are usually packed in heat sealable laminates containing a layer of layers of aluminium foil (Ranganna, 1994).

Economics of osmotic dehydration

In osmotic dehydration process, there is no phase change; hence there is less consumption of energy as compared to other drying process. It is less costly than freeze-drying process. The combination of osmotic process with air or vacuum drying was found to be less expensive than freeze-drying (Ponting *et al.*, 1966; Farksa and Lazer, 1969; Jackson and Mohammed, 1971). For economic purposes, lactose and maltodextrin were suggested as good substitutes for sucrose for food materials requiring less sweetenings. (Hawkes and Flink, 1978). It was also suggested that the syrup should be reconcentrated and reused for the process to be economically feasible. Bongirwar and Sreenivasan (1977), Bolin *et al*., (1983) and Le Maguer (1988) reported that osmotic 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.

Conclusion

Fresh fruit and vegetables contain 75 to 95% water and one way to reduce the water content initially is to use osmotic dehydration. The difference in osmotic pressure of the immersion solution and the product is the driving force of the process. The osmotic dehydration step can remove up to 50% of the water in the original fruit or vegetable. The product will lose water and most often gain solutes from the immersion solution. To achieve a stable product with a long shelf life requires a final stage of convection air-drying, vacuum drying or microwave-assisted drying. Pre-treatment with osmotic solution having concentrations lower than the natural cell concentration can improve the rehydration characteristics. Osmotic dehydration can also be used for the natural concentration of fruits, which helps in obtaining better characteristics of food prepared from them, such as jam. Application of various pre-treatments to osmotic dehydration such as high hydrostatic pressure, high electrical field pulses, gamma irradiation, ultrasound, vacuum and centrifugal force, can overcome the long existing issues related to the inherently slower mass transfer rates.

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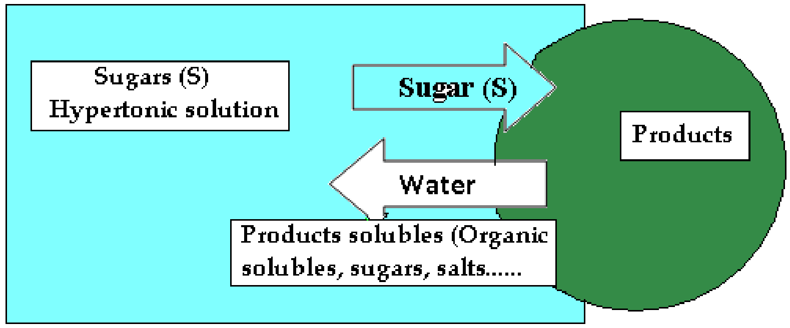

Fig. 1: Mass transport in osmotic dehydration

75.