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REVIEW ARTICLE

Vacuum Impregnation: Emerging Technology for Osmotic Dehydration and Value Addition in Fruits and Vegetables

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ABSTRACT

There is a great attention in recent years to develop an effective method for preservation of fruits and vegetables. Osmotic dehydration being simple process involves dehydration of fruits along with the retention of its aroma colour and nutritional compounds. Vacuum environment may be used to increase the rate of mass transfer. Vacuum Impregnation is emerging technology for osmotic dehydration having high rate of mass transfer due to the action of hydrodynamic mechanism promoted by pressure changes. It is a technique for introducing external liquids in void phase of foods sample in a controlled manner. It may be used to introduce several compounds to prolong shelf life, to enrich fresh food with nutritional and/or functional substances, to obtain innovative food formulations as pre-treatments before drying or freezing, etc. Anti-browning agents, firming agents, nutritional compounds, functional ingredients, antimicrobial agents, anti-freezing, enzymes, etc. serves the purposes. It is a useful technique to fill the void phase of foods with nutritional and functional ingredients. So the possibility to obtain foods with high nutritional and functional properties exponentially increases with this emerging technology. It was found to be a useful method to incorporate in void phase of foods cryoprotectants and cryostabilizers, such as hypertonic sugar solution, antifreeze protein (AFP), high methoxyl pectin, etc. which decreases the drip loss during thawing. One major issue is the large-scale industrial application of VI and other is the management of the remained solution at the end of the process. Other approaches need to be considered and requires a substantial research.

Keywords: Osmotic dehydration, HDM, Processing, Pro-biotic foods, shelf life.

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INTRODUCTION

Osmotic dehydration, being a simple process has achieved greater attention in recent years as an effective method for preservation of fruits and vegetables since they have largest number of pores to make favourable condition for osmotic dehydration. It facilitates processing of tropical fruits and vegetables such as banana, sapota, pineapple, mango, and leafy vegetables etc. with retention of initial fruit and vegetables characteristics viz., colour, aroma and nutritional compounds (Pokharkar and Prasad, 1998). It involves dehydration of fruit slices in two stages, removal of water using as an osmotic agent (osmotic concentration) and subsequent dehydration in a dryer where moisture content is further reduced to make the product shelf stable (Ponting, 1973). A further development in osmotic dehydration of foods is going on and vacuum impregnation (VI) is the newly developed one. VI of a porous product consists of exchanging the internal gas or liquid occluded in open pores to an external liquid phase due to the action of hydrodynamic mechanisms (HDM) promoted by pressure changes (Fito, 1994; Fito and Pastor, 1994). Even immersion of porous plant tissues in a liquid results in an influx of liquid due to capillary forces which are limited to close surface pores only. HDM (hydrodynamic mechanisms) describe the VI mass transfer phenomena

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and it is affected by the process duration, the process temperature, the sub atmospheric pressure level, the form and shape, the samples' mechanical response, the porosity, the size of the pores and the composition of the applied VI solution (Zhao and Xie, 2004). VI results in final product with a better organoleptic quality, texture, better nutrition, microbial safety. VI reduces discoloration due to removal of oxygen from the pores of the fruits and vegetables. A comparison of VI with the osmotic dehydration at atmospheric pressure in terms of time scale, driving force, controlling mechanism, equilibrium condition, water loss rate, solid gain is given below.

Table 1 Characteristics of a practical definition for different gas–liquid exchange processes

Process	Time scale	Driving force	Controlling mechanism	Equilibrium condition	Water loss rate	Solid gain
Vacuum impregnation	Minutes	Pressure gradients and capillary action	HDM	$\Delta P_{int-ext} = 0$	High	Low
Osmotic dehydration	Hours	Capillary action and chemical potential of components (mainly water)	PDM and CMD	$\Delta a_w = 0$	Middle	Middle

VI Process Mechanism

Dehydration involves the capillary flow and mass transfer. Plant tissue cells placed in different kinds of solution react differently. A) Isotonic solution: same solute concentration inside and outside the cell membrane. B) Hypotonic solution: less solute molecules outside of the cell membrane than inside of it. C) Hypertonic solution: more solute concentration outside the cell membrane than inside of it.

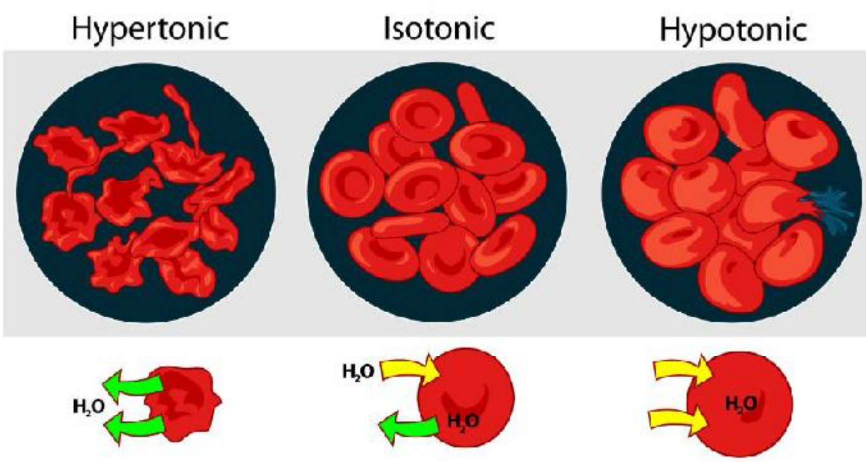

Figure 1 Type of impregnation solution and movement of water across the cell membrane (Source: www.studyblue.com)

VI simply intensifies the rate of capillary flow and mass transfer i.e. rate of dehydration. When porous structure is immersed in water then there is fast mass transfer and is termed as hydro dynamic mechanism (HDM). This involves the inflow of the external liquid throughout the capillary pores, controlled by the expansion/compression of the internal gas. When low pressure is imposed in solid liquid system followed by atmospheric pressure, hydro dynamic forces built up and responsible for VI processes for porous products (Fito et al., 2001; Zhao and Xie, 2004). It occurs in following two steps.

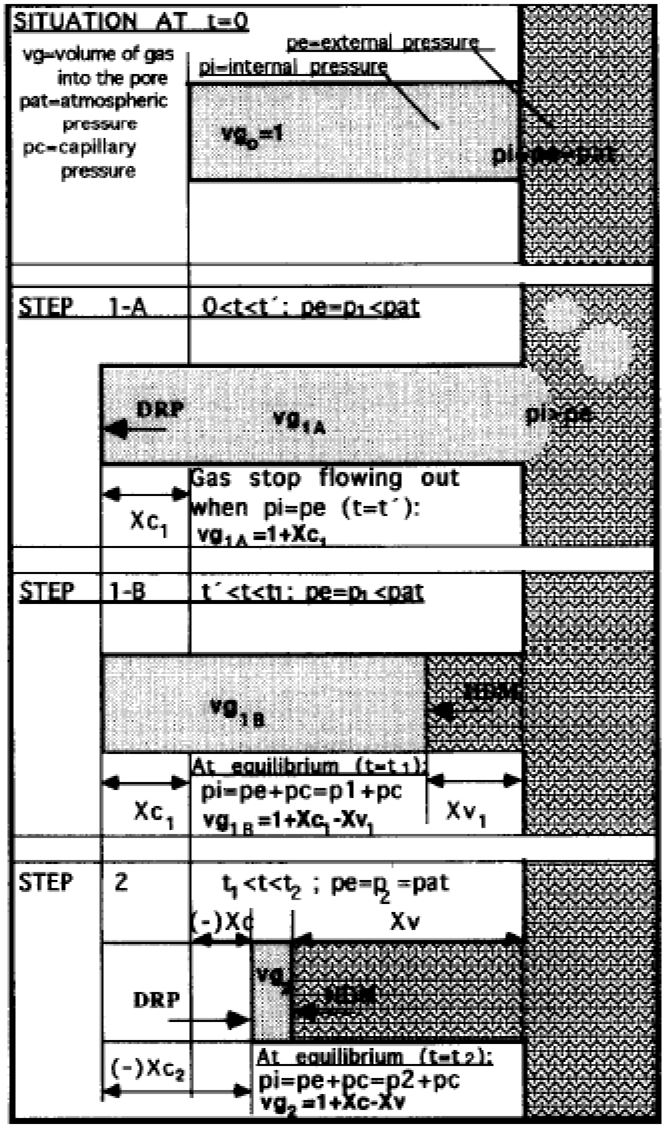

Figure 2 Solid food-liquid system, deformation-relaxation and HDM Path way in an ideal pore (Source: Fito etal., 1995)

Figure 2 schematically shows the phenomena involved during vacuum solid-liquid operations of an ideal pore. At time zero the samples are immersed into the external liquid and the internal pressure of the pore (p_i) is equal to external (atmospheric) pressure (p_e).

(a)Vacuum step

After, a vacuum pressure (p) is applied in the head space of the system for a time (t_1). This promotes a situation in which p_i is greater than p_e. In this condition, the internal gases expand producing the deformation (enlargement) of capillary and the increase of internal volume. Moreover, native liquids and gases partially flow out on the basis of the pressure gradient (step 1-

A). At this time hydrodynamic mechanism begins and external liquid partially flows inside the capillary as a consequence of the pressure gradient. These phenomena simultaneously occur until the equilibrium is reached (step 1-B).

(b) Atmospheric step

In the second step the atmospheric pressure in the head space of the system is restored and the samples are maintained into the solution for a relaxation time (t_2). During this period, the generated pressure gradient ($p_i < p_e$) promotes both HDM and solid matrix deformation (compression) which respectively produce capillary impregnation and the reduction of pore volume until a new equilibrium is reached (Fito and Chiralt, 1994; Fito et al., 1996).

After restoring the atmospheric pressure, the tissue contracts and it leads to volume reduction of the remaining gases and VI solution penetrates into the previously air-filled pores (Fito et al., 1996; Guillemin et al., 2008). Compression can also reduce the pore size depending upon the mechanical resistance of the solid matrix. The volume of externally penetrating liquid can account for almost the total volume of the intercellular space that was initially filled with gas (Fito, 1994) and the external liquid flows into the pores as a function of the compression ratio.

Pressure changes can also promote deformations of the product because of the visco-elastic properties of its solid matrix. Coupling of HDM with the deformation-relaxation phenomena (DRP) shows that volume changes at the end of the vacuum and the atmospheric steps and finally the effective porosity affects the volume fraction of the product impregnated by the external liquid.

VI as method to increase the rate of mass transfer of food during food processing

The main objective of several industrial processes is to extend the shelf life or to improve/change their nutritional, functional or sensorial properties. All these properties are based on mass transfer mechanism toward foods or vice versa. To increase the rate of mass transfer between food and an external solution as in the cases of osmotic dehydration acidification treatments, vacuum impregnation significantly increases the rate of the processes due to HDM and the increase of liquid-product contact area. A large literature concerning the effect of VI on the rate of osmotic dehydration recognized the effectiveness of VI (Shi and Fito, 1995; Fito et al., 1996; Rastogi et al., 1996; Tapia et al., 1999; Cunha et al., 2001; Moreno et al., 2004). Shi and Fito (1994) reported that water loss of apricot samples occurred much faster when vacuum was applied during the experiments. Shi et al. (1995) showed that osmotic dehydration under vacuum promotes faster water diffusion when apricots, pineapples and strawberries were treated. Rastogi et al. (1996), studying the kinetics of osmotic dehydration of apple and coconut samples showed that the estimated rates were significantly higher in vacuum conditions (235 mbar). Fito et al. (2001b) stated that VI promotes the effective diffusion in the fruit liquid phase when impregnated with low viscosity solution. Fito et al. (1994) found that water loss and solid gain obtained with a PVOD (VI treatment is carried out with the osmotic solution at the beginning of osmotic dehydration process is termed as pulsed Vacuum OD) treatment performed at 70 mbar with time of 5 minutes were greater than those obtained through a traditional Osmotic dehydration (OD).

VI brings with it a different structural development of the tissue response to mass transport. Differences in the structural features observed in vacuum impregnated and non impregnated samples have been explained in terms of the different pressure drop of liquid in the intercellular spaces flowing towards the volume generated by cell water loss, which is very different for gas or liquid phases in the intercellular space (Fito et al., 2000). Therefore VI pre-treatment may lead to a different drying behaviour of fruits and vegetables as well as to different final properties.

VI effects on physical properties

The product density is most affected by VI. It is due to fact that air in the pores is replaced by liquid hence density increases and thus affecting other related properties such as thermal conductivity but lesser modification in thermal diffusivity has been observed (Martinez Monzo et al., 1994). Highly porous product is highly affected by this process. These changes depend on total porosity and pore distribution in relation with the direction of heat flow and impregnating solution composition (Martinez Monzo et al., 2000; Barat et al., 1994). As impregnated solution concentration increases it promotes the expected reduction in all thermal properties as compared with impregnation without compositional changes (Fito et al., 2000). Gas liquid exchange in the product pores promoted by VI could improve microwave product interactions since in microwave drying operation heat generation and drying rate depends on the dielectric properties of material and so VI proves advantageous in microwave drying.

VI as method to improve food quality

It is previously discussed that vacuum impregnation is a technique for introducing external liquids in void phase of foods sample in a controlled manner. The term “external liquid” refers to a liquid obtained by dissolving any chemical components in water i.e. VI may be used to introduce several compounds to prolong shelf life, to enrich fresh food with nutritional and/or functional substances, to obtain innovative food formulations as pre-treatments before drying or freezing, etc. Anti-browning agents, firming agents, nutritional compounds, functional ingredients, antimicrobial agents, anti-freezing, enzymes, etc. serves the purpose. Sapers et al. (1990); Torreggiani, (1995); Barat et al. (2001) reported that the introduction of solutes such as antimicrobial, antibrowning and antioxidant improve the final quality of dried foods. Fito et al. (2001b) reported an improvement of the drying behaviour of several fruits and vegetables submitted to VI pre treatments. This pre-treatment also reduces the energy consumption and results into reduction of power cost. Several authors reported that the stability of pigments was enhanced without the use of common compounds for colour preservation when VI is applied before drying (Maltini et al., 1991; Torreggiani, 1995). Prothon et al. (2001) reported that water diffusivity of samples was increased when a pre-VI treatment was carried out. On the contrary, the same authors, studying the rehydration capacity of the samples, showed that this property was greater for non-treated samples, probably because both impregnation and DRP reduced the pores in which water flows during rehydration.

There is several stabilization processes, but the use of low temperatures i.e. freezing allows to better retain nutritional compounds in comparison with others traditional techniques such as dehydration, pasteurization/sterilization treatments, etc. However, in freezing process, the formation of ice crystals leads to several physical damage and drip loss during thawing. Fluctuation of temperature along the cold chain may promote recrystallization phenomena leading to changes in size and shape of ice as well as their orientation (Zhao and Xie, 2004; Cruz et al., 2009). Vacuum impregnation was found to be a useful method to incorporate in void phase of foods cryoprotectants and cryostabilizers, such as hypertonic sugar solution, antifreeze protein (AFP), high methoxyl pectin, etc. Martinez-Monzo et al. (1998) showed that as higher the concentration of sugar solution used during VI treatments, as lower the freezable water content in food. Lower freezable water content results into reducing the drip loss during thawing. The same authors studied the potential application of VI treatment to introduce concentrate grape musts and pectin solution with the aim to decrease the damages of freezing on apple samples. It was observed that the both aqueous solutions were effective in the reduction of drip loss during thawing. Xie and Zhao (2003) also showed that vacuum impregnation of strawberries and Marion berries with cryoprotectan solutions (HCFS and high methyl pectin) enriched with 7.5% of calcium gluconal highly enhanced the texture and the reduction of drip loss on frozen-thawed samples. Furthermore, the reduction of water content as a consequence of VI treatment reduces energy consumption during freezing.

Tapia et al. (1999) used a complex solution containing sucrose (40°Bx), phosphoric acid (0.6% w/w), potassium sorbate (100 ppm) and calcium lactate (0.2%) to increase the shelf life of melon samples. Results showed that foods packed in glass jars and covered with syrup maintained a good acceptance for 15 days at 25°C. Welty-Chanes et al. (1998) studying the feasibility of VI for the production of minimally processed oranges reported that the samples were microbiologically stable and showed good sensorial properties for 50 days when stored at temperature lower than 25°C. Derossi et al. (2010) and Derossi et al. (2011) proposed an innovative vacuum acidification (VA) and pulsed vacuum acidification (PVA) to improve the pH reduction of vegetable, with the aim to assure the inhibition of the out-grow of *Clostridium botulinum* spores in the production of canned food. The results stated the possibility to obtain a fast reduction of pH without the use of high temperature of acid solution as in the case of acidifying blanching. However, the authors reported the effect of VI on visual aspect of vegetable that need to be considered for the industrial application, because the compression deformation phenomena could reduce the consumer acceptability. Guillemin et al. (2008) showed the effectiveness of VI for the introduction of pectin methyl esterase which enhances fruit firmness.

VI as method for Value addition

Now a day consumers are vigilant towards the assumption of correct diet and its health benefits. So the possibility to obtain foods with high nutritional and functional properties exponentially increases the efforts of food scientists and industries in this research field. In this way, vacuum impregnation is a useful technique to fill the void phase of foods with nutritional and functional ingredients. However, the scientific results concerning this application of VI are still few. Fito et al. (2001a) were the first scientists that evaluated the feasibility of VI to obtain innovative fresh functional foods (FFF). They studied the impregnation of several vegetables with calcium and iron salt solution taking into account the solubility of these salts in water during their research. Hirinoka et al. (2011) studied the application of VI for the enrichment of whole potato with ascorbic acid. As expected ascorbic acid content significantly decrease (about 42%) after steam cooking. Nevertheless, VI-cooked samples had an acid ascorbic concentration 22 times higher than samples only submitted to steam cooking (raw-cooking). Furthermore, Xie and Zhao (2003) used VI to enrich apple, strawberry and Marion berry with calcium and zinc. The experiments performed with high corn syrup solution enriched with calcium and zinc showed that a 15-20% of RDI of calcium more than 40% RDI of zinc could be obtained in 200g of impregnated apple fresh-cut samples. Vacuum impregnation could be a method to produce a numerous series of innovative probiotic foods. For instance, Betoret et al. (2003) studied the use of VI to obtain probiotic enriched dried fruits.

However, despite the wide number of the potential industrial application, shelf life extension is one of the most important. So, due to its unique advantage vacuum impregnation may be considered useful methods to introduce inhibitors for microbial growth and/or chemical degradation reactions.

Suggestions for Future Studies

It is clear from above discussion that VI technique is considered to improve product quality, modify product formulation, and save energy in some of the fruit and vegetable processing. The specific application of VI can be controlled and optimized as per operating condition. However, extensive studies are still required in order to fully taking advantage of its unique features and applying in large-scale industrial operations. Optimal Mass transfer rate of VI solution should be essentially required to ensure sufficient solutes getting into the products without negative impacts on the physicochemical and sensory properties; especially when VI is used to develop compositionally formulated or minimally processed fruit and vegetable products. One major issue is the large-scale industrial application of VI and other is the management of the remained solution at the end of the process.. Unfortunately, the recycle of osmotic solution is still one of the main shortcomings and challenges. Techniques to treat the waste concentrated solutions, especially for the mixture solution, are very important and need more studies. If raw materials are contaminated, it may contaminate VI solutions during VI processing or if contaminated solutions are to be reused. Very little study was reported in this aspect, thus requiring a substantial research effort. VI processing requires complete immersion of the products under the solution and keeping the contact throughout the process. Current industry operation has used stirring or compressing for this purpose, but it adds more cost and may also damage the products. Other approaches need to be considered and requires a substantial research.

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