Revista Mexicana de Ciencias Agrícolas
REMEXCA
DOI: https://doi.org/10.29312/remexca.v14i8.2936
Essay

Incorporation of bioactive compounds in fruit and vegetable products through osmotic dehydration: a review

Karina Huerta-Vera[1]
Enrique Flores-Andrade[2]
Adriana Contreras-Oliva[3]
Ángel Villegas-Monter[1]
Sergio Chavez-Franco[1]
Ma. de Lourdes Arévalo-Galarza[1,§]

1 Campus Montecillo-Colegio de Postgraduados. Texcoco, Estado de México, México. CP. 56230. (karina.huerta@colpos.mx; avillega@colpos.mx; sergiocf@colpos.mx).

2 Universidad Veracruzana. Veracruz, México. CP. 94340. (enflores@uv.mx).

3 Campus Córdoba-Colegio de Postgraduados. Veracruz, México. CP. 94946. (adricon@colpos.mx).

Autora para correspondencia: larevalo@colpos.mx.

Abstract

The consumer is increasingly interested in their state of health and well-being, so the demand for functional foods has increased. The impregnation of bioactive compounds in fruit and vegetable products is a recent technology that opens a door of opportunity to a more demanding market, so a bibliographic review of the latest studies provides an overview for future work on the subject. The impregnation of bioactive compounds in the porous fraction of fruits and vegetables is achieved by osmotic dehydration (OD). In this sense, knowing the OD factors that determine the impregnation of bioactive compounds in plant tissues, their physicochemical stability during storage, and the latest trends in osmo-dehydrated fruit and vegetable products that could be considered functional foods is very important. Therefore, this review considered scientific information from different databases and was organized into three sections that are discussed: fundamentals of the OD, fruit and vegetable products enriched with bioactive compounds, and the physicochemical stability of these products during storage.

Palabras clave:

dehydrated foods, food stability, functional foods, impregnation.

DOI: https://doi.org/10.29312/remexca.v14i8.2936

Fruits and vegetables are an essential part of the human diet as they are a source of bioactive compounds such as vitamins, minerals, phytosterols, and dietary fiber, among others. Generally, fruits and vegetables are marketed fresh, however, their shelf life is limited due to their high metabolic activity, susceptibility to mechanical damage, and attack by microorganisms, which accelerate their senescence and death (Al-Tayyar *et al*., 2020).

Postharvest losses of fruits and vegetables represent between 40 and 50% of total food losses (Ferreira dos Santos *et al*., 2020). In this sense, dehydration is one of the most common conservation techniques since it reduces water activity (a_w) below 0.7. Dehydration methods include sun drying, hot air drying, vacuum drying, and freeze drying (Qiu *et al*., 2019).

In recent years, these treatments have been complemented with osmotic dehydration (OD), a pretreatment and process in which plant tissues are immersed in a hypertonic solution at a certain temperature and time, altering in a controlled manner the microstructural characteristics of the plant matrix, in which it is possible to impregnate bioactive compounds (minerals, vitamins, antioxidants, probiotics, fibers, etc.) in its porous fraction, which generates an additional benefit for the consumer.

OD reduces the adverse effects of heat from subsequent processes, improving product color, texture, and flavor, and minimizes production costs by maximizing energy efficiency (Ahmed *et al*., 2016). The following has been reported: impregnation of calcium and vitamins C and E in potato (*Solanum tuberosum* var. Diacol Capiro) (Duarte-Correa *et al*., 2020), the addition of antioxidants from beet juice in apple (*Malus domestica* L. cv. Granny Smith) (Aguirre-García *et al*., 2020), probiotics such as *Lactobacillus plantarum* in apple var. Royal Gala (Emser *et al*., 2017) and *Lactobacillus rhamnosus* in banana (*Musa paradisiaca* var. Tabasco) (Huerta-Vera *et al*., 2017), among others.

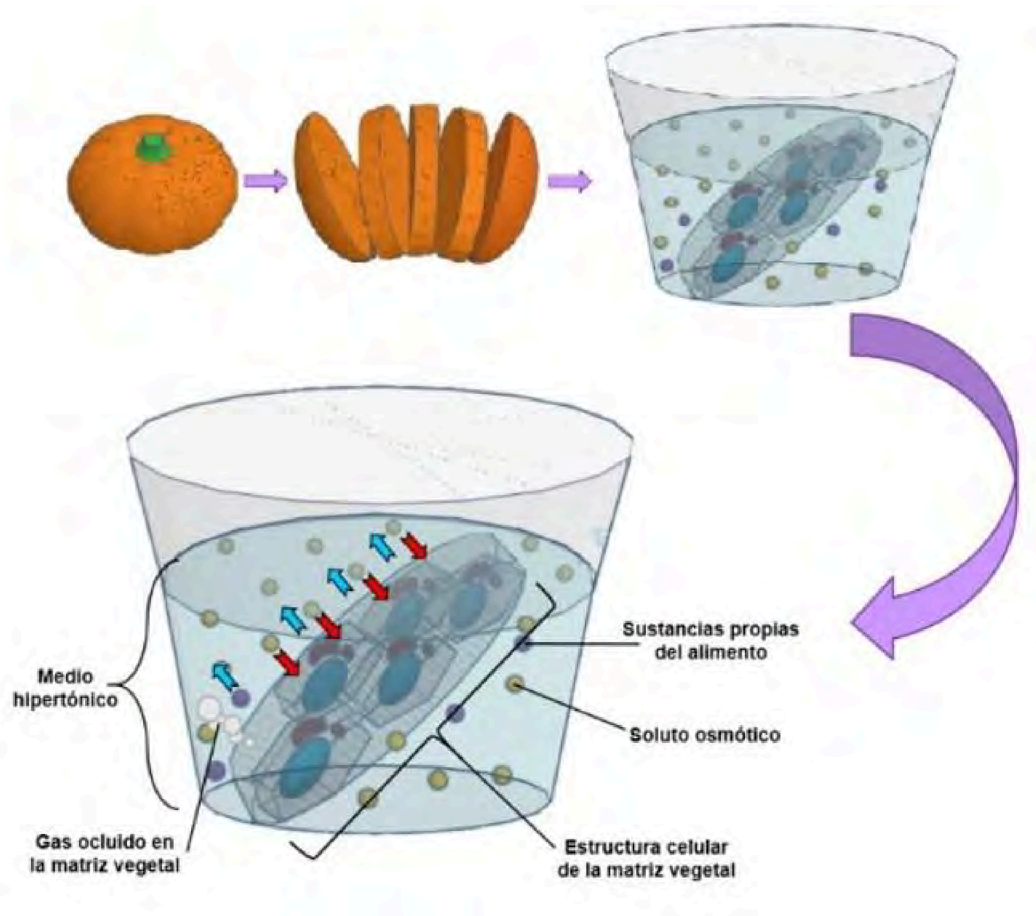
Therefore, this review analyzes the factors of osmotic dehydration that determine the incorporation of bioactive compounds in plant matrices; as well as recent trends in osmo-dehydrated fruit and vegetable products that could venture as functional foods and their physicochemical stability during storage.

Osmotic dehydration

OD is a processing technique that involves the immersion of food matrices in a hypertonic solution that induces three flows, i) the transfer of water from the product to the hypertonic solution, ii) the migration of osmotic solute into the product; and iii) leaching of cellular components of the product (sugars, acids, minerals, vitamins) into the hypertonic solution (Figure 1) (Ahmed *et al*., 2016; González-Pérez *et al*., 2019).

DOI: https://doi.org/10.29312/remexca.v14i8.2936

Figure 1. Mass transfer between plant tissue and hypertonic solution during osmotic dehydration. The blue arrows represent the transfer of water from the product to the hypertonic solution and the red arrows indicate the migration of osmotic solute into the product (Huerta-Vera, 2021).



The factors that determine the overall properties of mass transport during the osmotic process are.

Temperature

The increase in temperature during OD promotes mass transfer by decreasing the viscosity of the osmotic medium and increasing the permeability of membranes. When the process temperature exceeds the sensitivity of the product, excessive softening, enzymatic darkening, and loss of flavor and aroma occur (Xiao *et al*., 2018).

Hypertonic solution

It consists of high molecular weight solutes (sucrose) in high concentration, which optimizes the water loss (WL) of the product at the beginning of the process. When low molecular weight (glucose, fructose, sorbitol, etc.) and low concentration solutes are applied, solids gain (SG) is favored over WL (Xiao *et al*., 2018).

DOI: https://doi.org/10.29312/remexca.v14i8.2936

Contact between phases

The geometry and size of the product affect the specific surface (surface/volume ratio), a high specific surface favors solids gain (*SG*) in the product, while to generate greater WL and *SG*, it is necessary to have a greater surface area and smaller volume of the product (González-Pérez *et al*., 2019). Likewise, the use of high ratios of hypertonic solution: food (ε 20:1) prevents the dilution of the osmotic medium and the decrease of the concentration gradient during the process.

On the other hand, the use of stirring during the process ensures continuous contact of the product with the renewed hypertonic solution, which favors SG and WL; however, solids could form a thin layer on the tissue and act as a barrier that hinders subsequent *WL* of the product (Ahmed *et al*., 2016).

Product characteristics

The species, variety, and state of maturity define the complex and heterogeneous cellular structure of biological materials, with various physicochemical properties (fiber orientation, size of intercellular spaces, cell interconnectivity, pore space, soluble solids, water, etc.) that can facilitate or hinder the flow of mass during the osmotic process.

The pore space, or effective porosity ($\#_e$), is the fraction of the total volume of the plant matrix occupied by gas. Lech *et al*. (2018) analyzed the effect of ε_e on mass transfer during the OD of different fruit and vegetable species, showing that products with high ε_e, such as apple (var. Champion), parsley (*Petroselinum crispum* var. Eagle), and black radish (*Raphanus sativus* var. Sativus var. Kulata Cerna), present values of 26.75, 22.64 and 20.62%, respectively, which allows them a greater mass transfer during the osmotic process.

Conversely, products such as beet (*Beta vulgaris* var. Alto) and carrot (*Daucus carota* var. Nerac.) with a lower ε_e of 4.16 and 3.45%, respectively, presented lower mass transfer during the OD.

In this sense, Sulistyawati *et al*. (2018) report the effect of the maturity state of the fruit on the ε_e during OD in cubes of mango (*Mangifera indica* var. Kent.) treated with a solution of sucrose (60 °Brix), pectin methylesterase (PME) and calcium, reporting a higher *SG* in immature mango because it has more pore space compared to mature mango. Therefore, it is important to consider that the maturation process is not uniform in the product since there are different cell domains or clusters that contribute to the heterogeneity and anisotropy of the tissue, which will affect the OD process.

Cellular response to the osmotic process

Fruit and vegetable products have a complex composition distributed in four phases: solid matrix (cell wall, plasmalemma, tonoplast, and cell organelles in the cytoplasm), extracellular liquid phase, intracellular liquid phase and gas. A plant matrix contains up to 80% of spliced and interconnected parenchymal cells, with porous and thin cell wall (CW), a cytoplasm delimited by a membrane and a large central vacuole that can occupy up to 90% of a mature cell where water and nutrients are stored.

The CW is composed of microfibrils of cellulose, hemicellulose, and pectin that form intercellular spaces that confer certain mechanical properties to individual cells, such as stiffness. In particular, pectin has specific functions such as cell-cell adhesion and regulation of CW porosity (Winisdorffer *et al*., 2015).

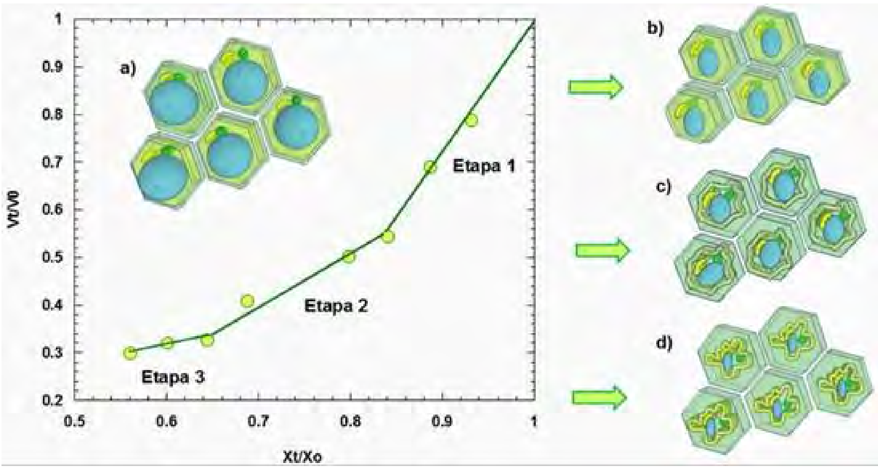
Three different routes have been described for mass flow through cell tissues during OD, i) apoplastic transport that takes place within the continuity of cell walls; ii) symplastic transport between adjacent cells via plasmodesmata; and iii) transmembrane transport; where water

DOI: https://doi.org/10.29312/remexca.v14i8.2936

diffusion is specifically mediated by aquaporins (proteins specialized in water transport) (Mauro *et al*., 2016).

During the OD of plant matrices, the parenchymal cells of the mesocarp go through three stages derived from the changes in volume (Vt/Vo) and moisture content (Xt/Xo) of the product (Figure 2) (Seguí *et al*., 2012). In stage 1, when the fresh plant matrix (Figure 2a) is immersed in a hypertonic solution, the chemical potential gradient generates the WL of the protoplast, which contracts and deforms along with the CW until the stretching forces result in incipient plasmolysis, the critical point where the plasma membrane begins to detach from the CW, consequently there is a cell shrinkage (Figure 2b).

Figure 2. Changes in volume (Vt/Vo) and moisture content (Xt/Xo) of slices of *virens levis* chayote fruit during osmotic dehydration in sucrose solution (50% at 35 °C). Fresh plant cells at the beginning of the process (a). Modifications at the cellular level during stages 1 (b); 2 (c); and 3 (d) of the osmotic process (Huerta-Vera, 2021).



During stage 2, mass flow through the plasma membrane increases the driving forces of stretching between the membrane and the CW until the membrane detaches and contracts elastically, generating new intracellular spaces that will be occupied by the hypertonic solution, thus promoting WL, which resulted in a decrease in moisture and volume in the product (Figure 2c).

Finally, in stage 3, the cell structure began to collapse derived from the complete separation between the plasma membrane and the CW, which allowed the protoplast to shrink freely. However, the CW and the Hechtian strands (thin cytoplasmic threads) continue to act as physical barriers to mass flow. At this stage, there was a slight reduction in volume; nevertheless, the entry of hypertonic solution into the cells caused the decrease in moisture content to continue (Figure 2d).

The modifications that occur in the cellular architecture of the plant matrix derived from WL and *SG* during OD are reflected macroscopically in the physicochemical properties of the product. Figure 3 presents three fruit and vegetable products osmo-dehydrated in sucrose solution (50 °Brix at 35 °C for up to 240 min), where it was appreciated that the elimination of water, in addition to reducing the moisture content and a_w of the product, also reduces its size and volume depending on the processing time.

DOI: https://doi.org/10.29312/remexca.v14i8.2936

Figure 3. Changes in the appearance of different fruit and vegetable products at different osmo-dehydra tiontimes with sucrose solution (50% at 35 °C) (Huerta-Vera, 2021).

Depending on the composition of the hypertonic solution, the *SG* will modify the color, flavor, and nutritional and functional properties of the product. On the other hand, the WL concentrates the pigments that provide color to the vegetable matrix, which can be seen as an increase in the purity and intensity of the color of the osmo-dehydrated product with respect to the fresh product.

In the case of melon, there is a transparency derived from the total or partial degassing of the air present in its tissue, which is replaced by the hypertonic solution; on the contrary, in apple and chayote, this transparency is not present, which may be due to the progressive formation of a sucrose bark on their surface.

Together, WL and *SG* decrease the elasticity and porosity of the product, which determine the texture characteristics of the product, resulting in a firm exterior and soft interior (Barragán-Iglesias *et al*., 2018).

Functional foods developed by OD

Functional foods are products modified by removing any of their components or integrating some bioactive compound (dietary fiber, oligosaccharides, polyols, peptides and proteins, isoprenoids and vitamins, lactic acid bacteria, minerals, unsaturated fatty acids, phytochemicals, and antioxidants) that has been scientifically proven to produce a benefit for the consumer (Fuentes-Berrio *et al*., 2015).

The OD allows altering in a controlled manner the microstructural characteristics of plant matrices by conferring the introduction of preservatives, flavorings, texture-enhancing agents, or bioactive compounds in their porous fraction through the use of multicomponent hypertonic solutions. Derived from this, the OD has been used for the development of new fruit and vegetable products.

Dehydrated slices of landrace mango and impregnated them with emulsions of oleoresin from piquín chili (*Capsicum annuum* L. var. Aviculare), which showed an antiproliferative effect on breast cancer cell lines MDA-MB-231, attributed to the synergy of capsaicin from piquín chili and bioactive components from mango pulp (Jiménez-Hernández *et al*., 2017).

Similarly, Shukla *et al*. (2019) dehydrated slices of mango cv. Fazli impregnated with emulsions of oleoresin from ginger (*Zingiber officinale*) to provide spicy flavor and antioxidant and anti-inflammatory properties; when comparing the product with a commercial one of similar

DOI: https://doi.org/10.29312/remexca.v14i8.2936

characteristics, they concluded that osmotic pretreatment improved the retention of vitamin C, total phenols and β-carotene by 60.2, 76.8 and 85.6%, respectively; in addition, they reduced the total processing time by up to 376.7%.

Authors such as Aguirre-García *et al*. (2020) impregnated antioxidant compounds of beet juice in slices of apple cv. Granny Smith, achieving an increase of up to 46 and 115% in total phenol content and antioxidant capacity, respectively, compared to the fresh product. Meanwhile, Barragán-Iglesias *et al*. (2018) dehydrated cubes of papaya (*Carica papaya* L. cv. Maradol) impregnated with calcium hydroxide ($Ca(OH)_2$), resulting in a product with a firm exterior and soft interior and reduced shrinkage and deformation, they also decreased drying time by up to 37%.

Lovera *et al*. (2018) studied the effect of impregnation of calcium lactate ($C_6H_{10}CaO_6$) and calcium gluconate ($C_{12}H_{22}CaO_{14}$) in papaya cylinders on the freezing time of the product, their results show that the OD allowed reducing the time and costs of production since the freezing time of the fruit in fresh, impregnated with calcium and osmo-dehydrated was 23, 17 and 5 min in tunnel, and 118, 83 and 60 min in a domestic freezer, respectively.

Since OD is very versatile, it has often been combined with other processing techniques in order to increase the mass transfer rate. In this sense, the application of high hydrostatic pressure (HP) generates compression and decompression of the product and leads to cell disintegration, which increases the cell permeabilization index (Zp) and mass flow during the osmotic process.

Research carried out by George *et al*. (2016) osmo-dehydrated slices of apple cv. Fuji with sucrose solutions and extract of kokum (*Garcinia indica*), their results showed a significant increase in the impregnation of kokum antioxidants in apples treated in a combination of HP and OD, compared to the product that was only processed by OD.

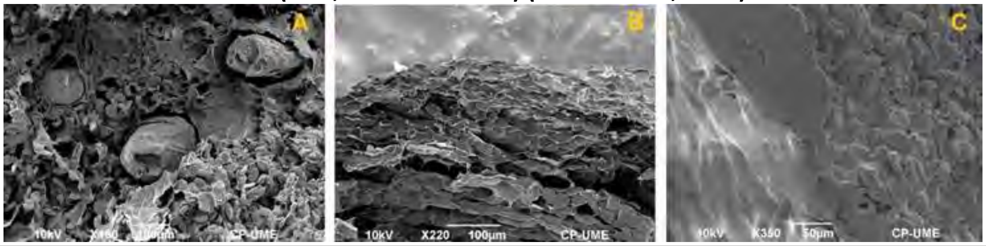
The OD has also been coupled with ultrasound (US), a process characterized by a vibration of air in a frequency range (20-100 MHz), and they have two alternating mechanisms: cavitation-compression and expansion, which cause erosion and decomposition of surface particles of the product, and lead to the formation of microscopic channels.

The use of US prior to OD has been studied by Maleki *et al*. (2020), who dehydrated carrot slices impregnated with phenolic compounds from the flower of roselle (*Hibiscus sabdariffa*), their results show that the maximum impregnation of phenolic compounds in the product was without US, this was attributed to prolonged US times damaging the microchannels of plant tissue and decreasing mass flow during OD. Subatmospheric pressures for a short time (5 to 20 min) have also been used, a technique known as vacuum impregnation (VI) and which, in combination with OD, is called pulsed vacuum osmotic dehydration (PVOD).

In Figure 4, it was observed how in the PVOD, the gas occluded in the pores of the plant tissue was eliminated until mechanical equilibrium was achieved, where once the atmospheric pressure is restored, the pores are filled with the external solution, which generates an increase in the product-hypertonic solution contact surface within the intercellular spaces of the plant tissue, and it causes structural modifications of the OD (Figure 4B), to a greater number of internal cells (Figure 4C), mainly in the outer cells of the product.

DOI: https://doi.org/10.29312/remexca.v14i8.2936

Figure 4. A) SEM micrographs of the structure of slices of Tabasco banana (Musa paradisiaca) without osmotic treatment; B) Slices with osmotic treatment at atmospheric pressure with sucrose solution (50%, 35 minat 35 °C); and C) Slices with osmotic treatment with 10 min vacuum pulse with sucrose solu tion (50%, 35 min at 35 °C) (Huerta-Vera, 2021).



Through VI and PVOD, various fruit and vegetable products impregnated with bioactive compounds have been formulated (Table 1). The PVOD has been widely used to enrich plant matrices with water-soluble bioactive compounds (antioxidants, water-soluble vitamins, minerals, etc).

Table 1. Plant matrices enriched with functional ingredients by vacuum impregnation (VI) or pulsed vacuum osmotic dehydration (PVOD).

Functional ingredient	Plant matrix	Reference
Minerals	Pineapple triangles enriched by VI with up to 24 487.3 µg g^{-1} (d.b.) of calcium chloride dihydrate.	Mateus de Lima *et al.* (2016)
Vitamins	*Diacol Capiro* potato slices enriched by VI with up to 72 and 53% vitamin E and C, respectively.	Duarte-Correa *et al.* (2020)
Antioxidants	*Tommy Atkins* mango slices impregnated with up to 3.34 mg GAE g^{-1} dm of grape extract polyphenols by PVOD. *Alba* strawberry halves enriched by VI with up to 22% cranberry juice polyphenols.	Batista de Medeiros *et al.* (2019) Tylewicz *et al.* (2019)
Probiotics	*Royal Gala* apple cubes impregnated by OD with up to 7 to 8 log_{10} (CFU g^{-1} db.) of *Lactobacillus plantarum*. *Tabasco* banana slices impregnated by OD and PVOD with up to 6 to 7 log_{10} (CFU g^{-1} db.) with *Lactobacillus rhamnosus*. ‘Granny Smith’ apple rings impregnated by VI with up to 7 to 8 log_{10} (CFU g^{-1} db.) with *Lactobacillus salivarius* spp. *salivarius*.	Emser *et al.* (2017) Huerta-Vera *et al.* (2017) Burca-Busaga *et al.* (2020)
Enzymes	‘Kent’ mango cubes impregnated by PVOD with pectin methylesterase (PME), which improved the firmness of the product.	Sulistyawati *et al*. (2018)

On the other hand, it has been possible to impregnate with viable probiotic bacteria such as *Lactobacillus* (*L. plantarum*, *L. rhamnosus*, *L. salivarius*, *L. casei*, among others) with and without barrier technologies against the effects of gastric juice and bile acid from the stomach. Emulsions (micro and nanoemulsions) have even been used as a strategy that allows the incorporation of bioactive compounds of lipophilic nature (fat-soluble vitamins, essential oils, oleoresins)

DOI: https://doi.org/10.29312/remexca.v14i8.2936

with application limited to products rich in fats and oils in water-rich foods such as fruits and vegetables.

The application of PVOD has been studied in various plant matrices and it has been observed that an important factor in the impregnation of solutes in plant tissue is its ε_e.

Physicochemical stability of osmo-dehydrated foods

Some studies have evaluated the physicochemical stability during the storage of osmo-dehydrated fruit and vegetable products impregnated with functional ingredients. The enrichment of plant matrices with compounds with antioxidant capacity prevents oxidative stress and damage to cellular structures (DNA, membrane proteins and lipids) that are related to neurodegenerative diseases.

Osmo-dehydrated cylinders of apple cv. Braeburn in solutions of sucrose and concentrated juice from aronia berries (*Aronia melanocarpa*) (120 min at 40 and 60 °C) and then dried them by lyophilization or convective air, and finally, vacuum packed in polyethylene bags to be stored (25, 35, and 45 °C) for 7 and 12 months (Cichowska and Kowalska, 2018). The results indicated that the product showed microbiological stability during and after storage regardless of the drying method, in addition, osmotic pretreatment induced a thermoprotective effect on the color of the product during storage.

Osmo-dehydrated slices of cucumber (*Cucumis sativus*) with hypertonic solutions of glycerol in combination with 20 different herbal infusions [chamomile (*Matricaria chamomilla* L.), oregano (*Origanum vulgare*), mint (*Mentha pulegium* L.), jasmine flowers (*Jasminum officinale*), turmeric (*Curcuma longa*)] rich in phenolic compounds and evaluated their quality during storage (37 °C), resulting in the osmo-treated product having a color, texture and microbiological evaluation two to almost four times higher than the untreated product (Giannakourou *et al*., 2019).

On the other hand, the enrichment of plant matrices with probiotics has been evaluated, which are live microorganisms that, when consumed in adequate quantities, inhibit the proliferation of pathogenic bacteria, improve the digestive process and the acquired immune response (Rascón *et al*., 2018).

Osmo-dehydrated cubes of apple var. *Royal Gala* with sucrose or sorbitol solutions (40 and 60 °Brix) containing *L. plantarum*, the apple cubes were stored (4 °C for 6 days) and evaluated by digestive simulation, their results exhibit a probiotic viability of 7 to 8 $\log_{10}$ (CFU g^{-1}) during storage with a survival of 7 $\log_{10}$ (CFU g^{-1}) during digestive simulation (Emser *et al*., 2017).

lyophilized slices of banana var. *Tabasco* enriched with *L. rhamnosus* using a sucrose solution (50 °Brix) and evaluated the effect of a_w (0.115 to 0.846) on the probiotic stability of the product during storage (25 °C for 42 days), their results show a bacterial viability of 6 to 7 $\log_{10}$ (CFU g^{-1} db) at low water activities (0.115 to 0.329) for a maximum period of 28 days (Rascón *et al*., 2018).

In addition to bioactive compounds, OD has also been useful in incorporating antimicrobial agents and flavor additives into plant matrices. Akharume *et al*. (2018) dried by convective air slices of apple var. Golden Delicious previously osmo-dehydrated with a solution of sucrose (42 °Brix) and refined liquid smoke and evaluated their color, texture, and microbial load during storage (150 days) in polyethylene bags with and without vacuum, their results show that apples with osmotic pretreatment with refined liquid smoke presented a characteristic brown coloration, better texture properties and a significant microbial reduction during storage compared to slices of apples dried by convection without osmotic pretreatment.

Conclusions

Studies show that through OD, with or without the implementation of other preservation techniques, it is possible to obtain fruit and vegetable products minimally processed and enriched with bioactive compounds with acceptable and sufficient physicochemical stability to exert a beneficial effect on the consumer.

DOI: https://doi.org/10.29312/remexca.v14i8.2936

However, fruit and vegetable products enriched with bioactive components by OD still face technological challenges and research opportunities that include: demonstrating their physicochemical stability during storage and the mechanisms of absorption and metabolism of the active ingredient in biological models. In addition, it is necessary to develop global policies that regulate and supervise the production and sale of functional foods in order to protect consumers from buying products with alleged attributions or properties beneficial to their health.

Bibliography

1 Aguirre-García, M.; Hernández-Carranza, P.; Cortés-Zavaleta, O.; Ruíz-Espinoza, H.; Ochoa-Velasco, C. E. and Ruíz-López, I. I. 2020. Mass transfer analysis of bioactive compounds in apple wedges impregnated with beetroot juice: a 3D modelling approach. J. Food Eng. 282:1-10. Doi: 10.1016/j.jfoodeng.2020.110003.

2 Ahmed, I.; Qazi, I. M. and Jamal, S. 2016. Developments in osmotic dehydration technique for the preservation of fruits and vegetables. Innovative Food Sci. Emerging Technol. 34:29-43. Doi:10.1016/j.ifset.2016.01.003.

3 Akharume, F.; Singh, K.; Jaczynski, J. and Sivanandan, L. 2018. Microbial shelf stability assessment of osmotically dehydrated smoky apples. LWT-food science and technology. 90:61-69. Doi: 10.1016/j.lwt.2017.12.012.

4 Al-Tayyar, N. A.; Youssef, A. M. and Al-Hindi, R. R. 2020. Edible coatings and antimicrobial nanoemulsions for enhancing shelf life and reducing foodborne pathogens of fruits and vegetables: a review. Sustainable Materials Technol. 26:1-11. Doi: 10.1016/j.susmat.2020.e00215.

5 Barragán-Iglesias, J.; Rodríguez-Ramírez, J.; Sablani, S. S. and Méndez-Lagunas, L. L. 2018. Texture analysis of dried papaya (*Carica papaya* L., cv. Maradol) pretreated with calcium and osmotic dehydration. J. Drying Technol. 37(7):906-919. Doi: 10.1080/07373937.2018.1473420.

6 Batista-Medeiros, R. A.; Da-Silva, J. E. V.; Fernandes-Silva, J. H.; Da-Cunha, F. N. O.; Rupert-Brand#o, S. C.; Pimenta-Barros, Z. M.; Sá-Rocha, O. R. and Moreira-Azoubel, P. 2019. E#ect of di#erent grape residues polyphenols impregnation techniques in mango. J. Food Eng. 262:1-8.

7 Burca-Busaga, C. G.; Betoret, N.; Seguí, L.; Betoret, E. and Barrera, C. 2020. Survival of *Lactobacillus salivarius* CECT 4063 and stability of antioxidant compounds in dried apple snacks as affected by the water activity, the addition of trehalose and high-pressure homogenization. Microorganisms. 8(8):1-15. Doi: 10.3390/microorga nisms8081095.

8 Cichowska, J. and Kowalska, H. 2018. Effect of osmotic pre-treatment and temperature storage conditions on water activity and colour of dried apple. Inter. J. Food Eng. 14(2):1-11. Doi: 10.1515/ijfe-2017-0158.

9 Duarte-Correa, Y.; Díaz-Osorio, A.; Osorio-Arias, J.; Sobral, P. J. A. and Vega-Castro, O. 2020. Development of forti#ed low-fat potato chips through vacuum impregnation and microwave vacuum drying. Innovative food science and emerging technologies. 64:1-11. Doi: 10.1016/j.ifset.2020.102437.

10 Emser, K.; Barbosa, J.; Teixeira, P. and Bernardo-Morais, A. M. M. 2017. *Lactobacillus plantarum* survival during the osmotic dehydration and storage of probiotic cut apple. J. Functional Foods. 38(A):519-528. Doi: 10.1016/j.jff.2017.09.021.

11 Ferreira-Santos, S.; Vieira-Cardoso, R. C.; Pereira-Borges, I. M.; Costel-Almeida, A.; Sodré-Andrade, E.; Ormonde-Ferreira, I. and Carmo-Ramos, L. 2020. Post-harvest losses of fruits and vegetables in supply centers in Salvador, Brazil: analysis of determinants, volumes, and reduction strategies. Waste Management. 101:161-170. Doi: 10.1016/j.wasman.2019.10.007.

DOI: https://doi.org/10.29312/remexca.v14i8.2936

12 Fuentes-Berrio, L.; Acevedo-Correa, D. y Gelvez-Ordoñez, V. M. 2015. Alimentos funcionales: Impacto y retos para el desarrollo y bienestar de la sociedad colombiana. Biotecnología en el sector agropecuario y agroindustrial. 13(2):140-149. Doi:10.18684/BSAA(13)140-149.

13 George, J. M.; Selvan, T. S. and Rastogi, N. K. 2016. High-pressure-assisted infusion of bioactive compounds in apple slices. Innovative food science and emerging technologies . 33:100-107. Doi: 10.1016/j.ifset.2015.11.010.

14 Giannakourou, M.; Strati, I. F.; Kriebardis, A. G.; Mantanika, V.; Poulis, S.; Zoumpoulakis, P. and Sinanoglou, V. J. 2019. Shelf-life extension and quality improvement of cucumber slices impregnated in infusions of edible herbs. J. Analytical Letters. 52(17):2677-2691. Doi: 10.1080/00032719.2019.1589476.

15 González-Pérez, J. E.; López-Méndez, E. M.; Luna-Guevara, J. J.; Ruíz-Espinosa, H., Ochoa-Velasco, C. E. and Ruíz-López, I. I. 2019. Analysis of mass transfer and morphometric characteristics of white mushroom (*Agaricus bisporus*) pilei during osmotic dehydration. J. Food Eng. 240:120-132. Doi: 10.1016/j.jfoodeng.2018. 07.026.

16 Huerta-Vera, K. 2021. Chayote osmodeshidratado y enriquecido con oleorresina de pimienta negra, tesis de doctorado, Colegio de Postgraduados, Montecillo, Texcoco, Estado de México. 2-25 pp.

17 Huerta-Vera, K.; Flores-Andrade, E.; Pérez-Sato, J. A.; Morales-Ramos, V.; Pascual-Pineda, L. A. and Contreras-Oliva, A. 2017. Enrichment of banana with *Lactobacillus rhamnosus* using double emulsion and osmotic dehydration. Food Bio. Technol. 10:1053-1062. Doi: 10.1007/s11947-017-1879-2.

18 Jiménez-Hernández, J.; Estrada-Bahena, E. B.; Maldonado-Astudillo, Y. I.; Talavera-Mendoza, O.; Arámbula-Villa, G. and Azuara, E. 2017. Osmotic dehydration of mango with impregnation of inulin and piquin-pepper oleoresin. LWT-food science and technology . 79:609-615. Doi: 10.1016/j.lwt.2016.11.016.

19 Lech, K.; Michalska, A.; Wojdy#o, A.; Nowicka, P. and Figiel, A. 2018. The in#uence of physical properties of selected plant materials on the process of osmotic dehydration. LWT-food science and technology . 91:588-594. Doi: 10.1016/j.lwt.2018.02.012.

20 Lovera, N. N.; Ramallo, L. and Salvadori, V. O. 2018. Effects of different freezing methods on calcium enriched papaya (*Carica papaya* L.). J. Food Sci. Technol. 55(6):2039-2047. Doi: 10.1007/s13197-018-3118-x.

21 Maleki, M.; Shahidi, F.; Varidi, M. J. and Azarpazhooh, E. 2020. Hot air-drying kinetics of novel functional carrot snack: Impregnated using polyphenolic rich osmotic solution with ultrasound pretreatment. J. Food Process Eng. 43(2):1-11. Doi: 10.1111/jfpe.13331.

22 Mateus-Lima, M.; Tribuzi, G.; Ribeiro-Souza, J. A.; Gon#alves-Souza, J. A.; Borges-Laurindo, J. and Mattar-Carciofi, B. A. 2016. Vacuum impregnation and drying of calcium-forti#ed pineapple snacks. LWT-food science and technology . 72:501-509. Doi: 10.1016/j.lwt.2016.05.016.

23 Mauro, M. A.; Dellarosa, N.; Tylewicz, U.; Tappi, S.; Laghi, L.; Rocculli, P. and Dalla, R. M. 2016. Calcium and ascorbic acid affect cellular structure and water mobility in apple tissue during osmotic dehydration in sucrose solutions. Food Chem. 195:19-28. Doi: 10.1016/j.foodchem.2015.04.096.

24 Qiu, L.; Zhang, M.; Tang, J.; Ahikari, B. and Cao, P. 2019. Innovative technologies for producing and preserving intermediate moisture foods: a review. Food Res. Inter. 116:90-102. Doi: 10.1016/j.foodres.2018.12.055.

25 Rascón, M. P.; Huerta-Vera, K.; Pascual-Pineda, L. A.; Contreras-Oliva, A.; Flores-Andrade, E.; Castillo-Morales, M.; Bonilla, E. and González-Morales, I. 2018. Osmotic dehydration assisted impregnation of *Lactobacillus rhamnosus* in banana and effect of water activity

DOI: https://doi.org/10.29312/remexca.v14i8.2936

on the storage stability of probiotic in the freeze-dried product. LWT-food science and technology . 92:490-496. Doi: 10.1016/j.lwt.2018. 02.074.

26 Seguí, L.; Fito, P. J. and Fito, P. 2012. Understanding osmotic dehydration of tissue structured foods by means of a cellular approach. J. Food Eng. 110(2):240-247. Doi: 10.1016/j.jfoodeng.2011.05.012.

27 Shukla, A.; Shukla, R. S.; Das, C. and Goud, V. V. 2019. Gingerols infusion and multi-step process optimization for enhancement of color, sensory and functional pro#les of candied mango. Food Chem. 300:1-10. Doi: 10.1016/j.foodchem.2019.125195.

28 Sulistyawati, I.; Dekker, M.; Fogliano, V. and Verkerk, R. 2018. Osmotic dehydration of mango: effect of vacuum impregnation, high pressure, pectin methylesterase and ripeness on quality. LWT-food science and technology . 98:179-186. Doi: 10.1016/ j.lwt.2018.08.032.

29 Tylewicz, U.; Mannozzi, C.; Romani, S.; Castagnini, J. M.; Samborska, K.; Rocculi, P. and Dalla, R. M. 2019. Chemical and physicochemical properties of semi-dried organic strawberries enriched with bilberry juice-based solution. LWT-food science and technology . 114:108377. Doi: 10.1016/j.lwt.2019.108377.

30 Winisdorffer, G.; Musse, M.; Quellec, S.; Barbacci, A.; Le-Gall, S.; Mariette, F. and Lahaye, M. 2015. Analysis of the dynamic mechanical properties of apple tissue and relationships with the intracellular water status, gas distribution, histological properties, and chemical composition analysis of the dynamic mechanical properties of apple tissue and relationships with the intracellular water status, gas distribution, histological properties and chemical composition. Postharvest Biol. Technol. 104:1-16. Doi: 10.1016/ j.postharvbio.2015.02.010.

31 Xiao, M.; Bi, J.; Yi, J.; Zhao, Y.; Peng, J.; Zhou, L. and Chen, Q. 2018. Osmotic pretreatment for instant controlled pressure drops dried apple chips: Impact of the type of saccharides and treatment conditions. Drying Technology. 37(7):1-10. Doi: 10.1080/07373937.2018.1473419.

Incorporation of bioactive compounds in fruit and vegetable products through osmotic dehydration: a review

Journal Information
Journal ID (publisher-id): remexca
Title: Revista mexicana de ciencias agrícolas
Abbreviated Title: Rev. Mex. Cienc. Agríc
ISSN (print): 2007-0934
Publisher: Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias

Article/Issue Information
Date received: 01 June 2023
Date accepted: 01 August 2023
Publication date: 12 Enero 2024
Publication date: October 2023
Volume: 14
Issue: 8
Electronic Location Identifier: e2936
DOI: 10.29312/remexca.v14i8.2936

Categories

Subject: Ensayo

Keywords:

Keywords:

dehydrated foods
food stability
functional foods
impregnation

Counts

Figures: 4
Tables: 1
Equations: 0
References: 31
Pages: 0