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Advancements in thermal and nonthermal process-assisted osmotic dehydration: A comprehensive review on current technologies for enhancing the quality of foods

Kulwinder Kaur[1,2], Baldev Singh Kalsi[3], Ruchika Zalpouri[3,4]*, Pratik Pandit Potdar[5], Sajeev Rattan Sharma[3], Mohammed Shafiq Alam[3], R. Pandiselvam[6]

[1]Department of Food Technology and Nutrition, Lovely Professional University, Phagwara, Punjab, India; [2]Department of Food Technology, Dr. Rajendra Prasad Central Agricultural University, Pusa, Bihar, India; [3]Department of Processing and Food Engineering, Punjab Agricultural University, Ludhiana, Punjab, India; [4]BANC Biopolymers Private Limited, Ludhiana, Punjab, India; [5]Maharashtra Institute of Technology (Autonomous), Chhatrapati Sambhaji Nagar, Maharashtra, India; [6]Physiology, Biochemistry and Post-Harvest Technology Division, ICAR – Central Plantation Crops Research Institute, Kasaragod, Kerala, India

***Corresponding Author:** Ruchika Zalpouri, Department of Processing and Food Engineering, Punjab Agricultural University, Ludhiana, Punjab, India. Email: zalpouri28@gmail.com

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REVIEW PAPER

Abstract

Osmotic dehydration (OD), a process driven by water-solute diffusion, has emerged as a sustainable method of food preservation, reducing water activity without phase change, thereby extending shelf life and improving food quality. Unlike traditional drying, recent technological advancements have significantly enhanced OD efficiency, shortened processing times, and reduced energy consumption by integrating innovative thermal and nonthermal methods, such as ultrasound, pulsed electric fields, high-pressure processing, ohmic heating, and pulsed vacuum osmotic dehydration. These hybrid approaches accelerate dehydration, enhance retention of bioactive compounds, and improve nutritional, sensory as well as microbial attributes. The use of membrane technologies and optimized process parameters further supports the sustainability and scalability of OD methods. Despite these innovations, challenges remain, including process standardization, solution management, and industrial feasibility. This review summarizes the principles, recent technological advancements, and potential future directions in OD; it highlights its potential for sustainable, energy-efficient, and consumer-preferred food products as well as broader industrial adoption with improved food security.

Keywords: dehydration; fruits and vegetables; nonthermal technologies; osmotic; quality

Introduction

The preservation and extended shelf life of food are significantly influenced by water activity. A practical strategy to achieve this is by decreasing the moisture content in fruits and vegetables (Pandiselvam *et al.*, 2021; Zalpouri *et al.*, 2020). Water significantly influences both chemical properties of food and its sensory attributes, which are critical for consumer satisfaction. Dehydration, one of the oldest and most widely adopted food preservation techniques, involves removing moisture to a level where water activity is sufficiently reduced (Borse *et al.*, 2024; Kaur *et al.*, 2024; Zalpouri *et al.*, 2022). This reduction in water activity helps to prevent concurrent microbial and enzymatic activities, thereby preserving quality of the product (Kaur *et al.*, 2016; Pravitha *et al.*, 2021).

However, while drying methods are effective in extending the shelf life of food, they can significantly affect the quality of the final product (Kaur *et al.*, 2023). Common quality issues associated with dehydrated products include challenges in reconstitution, alterations in textural properties, and loss of nutritional and sensory attributes, such as flavor, color, and taste (Kumar *et al.*, 2023). These defects often stem from exposure to high drying temperatures and prolonged drying durations (Delfiya *et al.*, 2022; Jeevarathinam *et al.*, 2021). Considering these facts, several new methods for improving dried food quality have been explored; osmotic dehydration (OD) has been demonstrated to be an effective pretreatment prior to regular drying (Kutlu *et al.*, 2022; Pravitha *et al.*, 2022). The OD process is receiving increasing attention as a complementary technique in foodstuffs, as it has the potential to improve quality and reduce energy consumption (Kaur *et al.*, 2022).

In the OD process, plant tissue undergoes immersion in a hypertonic solution to facilitate the partial removal of moisture (Kaur *et al.*, 2020, 2022). This hypertonic solution comprises osmotic constituents that draw water from the cell tissues, occupying the space between the cell wall and cell membrane (Ciurzyńska *et al.*, 2016). The elevated osmotic pressure and reduced water activity of the osmotic solution generally drive the transfer of water from the cells into the solution (Figure 1; Zeeshan *et al.*, 2016). At the same time, solutes from the osmotic solution diffuse into the cell tissues, creating a counter-movement (Abrahão and Corrêa, 2023; Manzoor *et al.*, 2023). It is noteworthy that the cell membrane, responsible for osmotic transport, may not exhibit perfect selectivity; other solutes, such as sugar, organic acids, minerals, and vitamins, present in the cell can diffuse into osmotic solution (Ramya *et al.*, 2017). While the quantities of these solutes that diffuse may be relatively small compared to water transfer, they can still impact quality of the final product. Osmotic pressure is an equilibrium force between a solution and a solvent, expressed as follows:

$$\Pi = \frac{-R \times T \times \ln(a_w)}{V}, \tag{1}$$

where Π represents the osmotic pressure, V is the molar volume of water (measured in liters), R is the gas constant (in Nm/mol K), T denotes the absolute temperature (in Kelvin), and a_w is the water activity coefficient. Variation in osmotic pressure between two systems gives rise to mass transfer phenomena, namely the osmotic dewatering of fruits and vegetables, along with the counter-diffusion of solutes toward the cell wall (Ramya *et al.*, 2017).

Osmotic dehydration is a widely recognized technique for reducing moisture content in food while preserving its quality (Ranjani *et al.*, 2024). This technique efficiently inhibits oxidative browning and preserves volatile flavor compounds, helping to maintain the sensory qualities and physicochemical properties of the product. Additionally, it is an energy-efficient process that does not require chemical additives to prevent enzymatic or oxidative browning (Kaur *et al.*, 2022; Sriraaman *et al.*, 2021). Another key advantage is reduction in both weight and volume, which simplifies storage and transportation. However, despite these benefits, certain challenges limit its large-scale industrial adoption. Managing the osmotic solution remains a challenge, and for some products, the formation of an undesirable sugar coating necessitates immediate rinsing post-treatment. Additionally, the quality of hypertonic solution can deteriorate over time because of the leaching of soluble from the product. Large-scale implementation is further constrained by the formation of a concentrated solid layer, which influences sugar content, flavor retention, and rehydration properties. Addressing these limitations through process optimization and technological advancements could improve the feasibility of OD for industrial applications (Abrahão and Corrêa, 2023; Bashir *et al.*, 2020; Shete *et al.*, 2018).

Mechanism Involved in Osmotic Dehydration

The extracellular volume is composed of the wall of the cell and the space between the cells. Several pathways contribute to OD, including symplastic (transport within the intracellular volume), free space (transport through extracellular space), and apoplastic (transfer across plasma membranes). During osmosis, water is primarily removed via diffusion and capillary flow, while solutes are only absorbed or leached through diffusion. Consequently, the placement of a food material in a hypertonic solution generates a concentration gradient between the hypertonic solution and the cells. The initial cell layer in direct contact with the solution starts to lose water, leading to the contraction or shrinkage of the material. Upon losing water from the first layer of the cell, the cells in the second layer develop a chemical potential difference in water. This makes the water in the second layer move toward the first layer, causing the cell to shrink. Consequently, the process of mass transfer and tissue shrinkage progresses from the surface to the center of the material until significant water loss occurs at the core of the material. The mass transfer flux is likely to reach equilibrium after an extended contact period between the liquid and solid phases (Bashir *et al.*, 2020; Shete *et al.*, 2018). The OD process induces concurrent tissue shrinkage and mass transfer, leading to changes in mechanical properties and structural deformation. Additionally, the nonselective nature of the cell membrane allows organic acids, minerals, sugars, colorants, and fragrances to potentially flow directly into the hypertonic solution (Rastogi *et al.*, 2014). Sucrose,

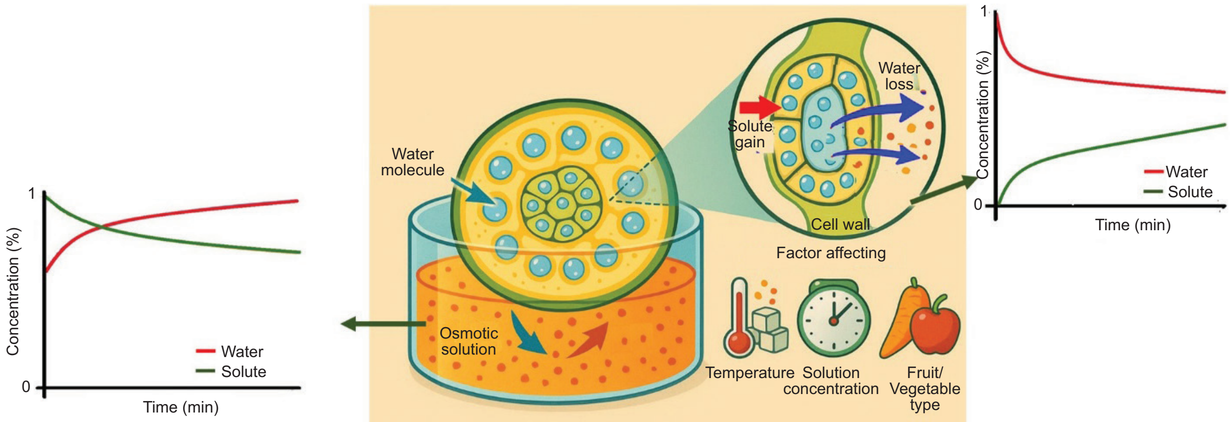

Figure 1. Mechanism involved during osmosis. (Source: Asghari *et al.*, 2024)

glucose, and fructose syrups are widely used in OD of fruits and vegetables but can raise blood sugar levels, making them unsuitable for diabetic consumers (Cozma and Sievenpiper, 2014; Mari *et al.*, 2024). Sodium chloride (NaCl) is effective for vegetable dehydration but imparts a salty taste, limiting its use in fruits (Bashir *et al.*, 2020; Kaur *et al.*, 2020). Fruit juices and by-product extracts are increasingly being utilized for their rich bioactive compounds and flavor-enhancing properties, thereby enhancing the overall product quality (Kowalska *et al.*, 2023; Rastogi *et al.*, 2014; Yazidi *et al.*, 2024). Polyols (xylitol, sorbitol, erythritol, and maltitol) offer low-calorie alternatives with dental benefits but may alter snack sensory attributes (Cichowska *et al.*, 2018; Corrêa *et al.*, 2021; Ding and Yang, 2021). Additionally, polyols have a lower caloric value than sucrose because of their poor absorption in the gut, which can benefit people who struggle with diabetes or obesity (Barba *et al.*, 2024; Mendonça *et al.*, 2017; Rice *et al.*, 2020). Jaggery, a nutrient-rich unrefined sugar, is emerging as a healthier alternative, enhancing the mineral content and antioxidant properties of osmotic-dehydrated fruits (Barrera *et al.*, 2024; Kaur *et al.*, 2024). Honey, recognized for its ability to inhibit enzymatic browning, also boosts the sensory characteristics of the product (Chavan and Amarowicz, 2012; Kaur, 2022). Emerging agents, such as sugar beet molasses and concentrated fruit juices, have shown potential for natural fortification, enriching the final product with essential minerals, such as calcium, potassium, and magnesium (Haneef *et al.*, 2024; Silva *et al.*, 2014). In recent years, concentrated juices have been proposed as alternative osmotic agents because they are natural sources of nutritional compounds (Chambi *et al.*, 2016; Jiménez *et al.*, 2020; Samborska *et al.*, 2019). Stevia and tagatose, with their low glycemic index and therapeutic properties, are also being explored for healthier OD applications (Ranjani *et al.*, 2024; Rubio-Arraez *et al.*, 2015). Table 1 provides an overview on the effects of various hypertonic solutions on final products.

Advancements in Osmotic Dehydration for Improved Mass Transfer Processes

Traditionally, food preservation has relied on thermal methods. However, heat treatment often compromises the nutritional value, appearance, and flavor of food. To achieve effective microbial reduction while preserving food quality, various nonthermal techniques have been developed, including the use of hydrostatic pressure and pulsed electric fields (PEFs). OD, being a slower process, has prompted the exploration of additional methods to enhance mass transfer without adversely affecting product quality. Several approaches, such as ultrasound, high hydrostatic pressure, PEFs, vacuum, centrifugal force, and microwaves (MW), have been employed to accelerate mass transfer rates.

Ultrasound-assisted osmotic dehydration (UAOD)

Osmo-sonication refers to a combination of OD and ultrasound applied to food products (Osae *et al.*, 2019). By employing an ultrasonic probe or an ultrasonic bath, mechanical waves with frequencies of 20 kHz and 1 MHz are applied to either aqueous media or food immersed in a hypertonic solution (Figure 2). Various ultrasound-assisted methods include pretreatment with ultrasound, airborne ultrasound-assisted drying, and contacting ultrasound-assisted drying. The utilization of low-frequency ultrasound (20–100 kHz) and high-energy ultrasound induces a rapid cycle of expansion and compression, resulting in alterations to cellular structure, ultimately reducing the moisture (Kalsi *et al.*, 2022, 2023). Wu *et al.* (2020) examined the effect of ultrasound on the increase of mass transfer and the reduction of drying time by 20–50% following OD of Pakchoi stems. In addition to increasing water loss, both OD and ultrasound enhance phenolic and antioxidant concentration in sucrose (Rahaman *et al.*, 2019).

Table 1. Osmotic agents and their effects.

Osmotic agent	Product	Processing condition	Effect	References
Sugar solution containing anthocyanin extract	Watermelon rind	• Osmosis solution concentration: Sugar (30–70°Brix) with anthocyanin extract at 5–6°Brix • Osmosis time: 4 h	The developed product had a crunchier texture because of sugar infusion and higher chroma because of added anthocyanin during the process, which resulted in higher sensory attributes	Bellary *et al.*, 2016
Concentrated juices (red grape juice)	Yellow melon	• Osmosis solution concentration: 60°Brix • Osmotic solution temperature: 40°C	The osmotic dehydration with grape juice concentrate was the most effective one, with higher dehydration and the lowest solute gain (WL/SG of 11.2±3.0), compared to the process carried out with sucrose solution	Chambi *et al.*, 2016
Oligosaccharides	Pumpkin	• Osmosis solution concentration: oligofructose and mixture of sucrose–oligofructose 1:1 with 70° Brix • Osmotic solution temperature: 75°C, 85°C, and 95°C • Osmosis time: 240 min	Oligofructose and the mixture of sucrose and oligofructose showed the highest level of water loss, while the OD solution containing merely oligofructose led to the highest increase in soluble solids	Katsoufi *et al.*, 2017
Honey	Pineapple (slices)	• Osmotic solution concentration: 50°Brix • Osmosis time: 24 h	The highest sensory score was recorded at 6-mm thick pineapple slices. The lowest sensory score at 12-mm thick pineapple slices	Mahesh *et al.*, 2017
Polyols solutions (erythritol, xylitol, and maltitol)	Apples	• Osmosis solution concentration: 20%, 30%, and 40% • Osmotic solution temperature: 40°C • Osmosis time: 6 h	Low-calorie sweeteners with properties similar to sugar. They benefit diabetic and obese individuals because of poor absorption in the gut. OD in inulin (INU) and oligofructose was ineffective—the observed values of WL were low while the highest WL during OD was in maltitol even at 20% concentration	Cichowska *et al.*, 2018
Sucrose	Kiwi	• Osmosis solution concentration: 45, 55, and 65°Brix • Osmotic solution temperature: 25°C • Osmosis time: 300 min	Water activity decrease was higher when the product was in 65°Brix solution	Brochier *et al.*, 2019
Stevia	Tomatoes	• Osmotic solution temperature: 75°C, 85°C, and 95°C • Osmosis time: 180 min • Osmotic solution concentration: 65, 70, and 75°Brix	Calorie-free sweetener with 15 times the sweetening power of sucrose. Exhibits antioxidant, antimicrobial, antifungal, anti-hyperglycemic, antihypertensive, anti-inflammatory, antitumor, anti-diarrheal, and diuretic properties	Giannakourou *et al.*, 2020b; Lazou *et al.*, 2020
Salt	Potatoes	• Osmosis solution concentration: 10%, 15%, and 20% • Osmotic solution temperature: 40°C • Osmosis time: 4 h	Inhibited both oxidative and nonenzymatic browning. Facilitated water loss (23.85%) and solute gain (20.53%) transfer and prevented surface shrinkage	Hawa *et al.*, 2020
NaCl solution and sucrose	Peas	• Osmosis solution concentration: NaCl: 10% (w/w), sucrose: 10°Brix, and mixed solution: 10% (w/w) NaCl and 10°Brix sucrose • Osmotic solution temperature: 30°C, 40°C, and 50°C • Osmosis time: 2.5 h	Drying of fresh green peas subjected to osmotic pre-treatment at optimized conditions, followed by three-stage convective drying, yielded dried peas with low moisture content, minimal color change, and sufficient sphericity and hardness	Kaur *et al.*, 2020
Concentrated juices (chokeberry, flowering quince, and raspberry concentrated juices)	Pumpkin	• Osmosis solution concentration: 40°Brix and 45°C • Osmosis time: 0.5 h, 1 h, 2 h, 3 h, and 6 h	The bioactivity of samples improved significantly, particularly in terms of polyphenol content and antioxidant activity. The highest levels of polyphenolic compounds and the strongest antioxidant capacity were observed when flowering quince concentrated juice was used for osmotic dehydration	Lech *et al.*, 2020

(*continues*)

Table 1. Continued.

Osmotic agent	Product	Processing condition	Effect	References
Calcium chloride	Melon chips	• Osmosis solution concentration: 2 g 100 mL^{-1} • Osmotic solution temperature: 25°C	The vacuum-impregnated (VI) melons presented higher mass gain and drying time. It resulted in the highest calcium incorporation, increasing up to 13 times the calcium concentration of the samples	da Silva Barros de Oliveira *et al.*, 2021
Jaggery and coconut sugar	Coconut	• Osmosis solution concentration: 45–55°Brix	Coconut sugar-treated and jaggery-treated chips were observed to be more visually appealing than sucrose-based samples. Coconut sugar exhibited the values of the mass transfer of solute and water during osmotic dehydration and convective drying	Pravitha *et al.*, 2021, 2022
Glycerol (GLY) and INU	Plums	• Osmosis solution concentration: INU (50–100 g); GLY (200–400 g) • Osmotic solution temperature: 60°C • Osmosis time: 240 min	INU (100 g) and GLY (219 g) resulted in water loss (WL) and water retention (WR) values of 30% and 29%, respectively, along with INU and GLY gain of 119 mg/g and 373 mg/g, respectively	Palacios Romero *et al.*, 2022
Lactose	Zucchini	• Osmosis solution concentration: 30%, 40%, and 50% (w/v) • Osmotic solution temperature: 26°C • Osmosis time: 2 h	Lactose at 49.99% yielded 5.88 g/g idm moisture loss, 0.872 g/g idm sucrose absorption, and 0.704 g/g idm moisture content	Rahman *et al.*, 2022
Coconut sugar	Strawberries	• Osmosis solution concentration: 40% and 60% (w/w) • Osmosis time: 300 min	SG, WL, and WR increased over the OD time and showed values of up to 7.94%, 63.40%, and 55.94%, respectively, and maintenance of acidity, anthocyanins, AA, total phenolics, and antioxidants Healthier alternative to sucrose and jaggery. Has a lower glycemic index (35–42), compared to jaggery (84.1) and sucrose (82), making it suitable for diabetic individuals	Macedo *et al.*, 2023
Sucrose with pea protein isolate (PPI)	Apple slices	• Osmosis solution concentration: sucrose at 40% wt with 3% wt PPI • Osmotic solution temperature: 40°C • Osmosis time: 4 h	Reduced sugar or sucrose uptake by product from 51.79 mg/100 g to 46.12 mg/100 mg dry basis, preventing health risk because of elevated sugar level	Wang *et al.*, 2023
Sucrose with INU	Apple slices	• Osmosis solution concentration: Sucrose at 40% with 1.5% wt INU • Osmotic solution temperature: 40°C • Osmosis time: 4 h	Reduced sugar or sucrose uptake by product from 51.79 mg/100 g to 43.43 mg/100 mg dry basis, preventing health risk because of elevated sugar level	Wang *et al.*, 2023
Isomaltulose	Papaya	• Osmosis solution concentration: 35% w/w • Osmosis time: 300 min with vacuum application at 80 kPa for the first 20 min and immersed in 95% ethanol for 2 min	30% reduction for a total drying time of 240 min in convective drying along with lower shrinkage, hardness, and effective diffusivity	Cruz *et al.*, 2025
Sugar beet molasses	Beetroot	• Osmosis solution concentration: 40%, 60%, and 80% • Osmotic solution temperature: 20°C, 40°C, and 60°C • Osmosis time: 1 h, 3 h, and 5 h	Enhances the product quality at temperature 60°C, molasses concentration 70%, and processing time 5 h	Šuput *et al.*, 2024
Sucrose with jaggery	Pineapple	• Osmosis solution concentration: 60°Brix • Osmosis time: 5 h	Water loss (32.3%) and weight reduction (24.9%) with the overall acceptable quality	Siwach *et al.*, 2025

Notes: g/g idm: grams of water per gram of initial dry matter; AA: ascorbic acid; SG: solid gain; WL: water loss; WR: water retention; OD: osmotic dehydration.

Nowacka *et al.* (2017) reported that kiwifruit retained chlorophyll after osmo-sonication. As a result of the collapse of small cavitation bubbles, free radicals are formed, namely H+ and OH-, which may accelerate certain chemical reactions and form extra molecules, thus leading to a risk of radicals destroying bioactive compounds, for example, phenol. Heat-sensitive compounds could be preserved by using ultrasound-assisted low-temperature drying. Additionally, ultrasound treatments are easy to perform and offer the benefit of enhancing OD efficiency and speed (Nowacka *et al.*, 2021). Bozkir *et al.* (2019) conducted a research study in which the influence of ultrasound and OD as pretreatments on the drying behavior and quality of persimmon fruit was studied. UAOD, particularly when applied for 30 min, led to faster drying, increased water loss, and improved water diffusivity, while maintaining color properties similar to untreated samples. Memis *et al.* (2023) conducted a study in which response surface methodology (RSM) was employed to optimize the efficiency of ultrasonic-assisted OD, combined with subsequent MW drying for beetroot, resulting in improved color and the preservation of antioxidant properties. Both pretreatment and MW drying methods ensured product quality, and increasing MW power levels were observed to enhance diffusion coefficients. Table 2 displays the impact of treatment conditions in UAOD on the quality characteristics of various products.

Gamma irradiation and osmotic dehydration

The Food and Agriculture Organization (FAO) has deemed gamma irradiation at doses of up to 10 kGy as safe (Asghari *et al.*, 2024). This process induces structural modifications in food tissues, resulting in membrane permeabilization and improved mass transfer during OD (Ahmed *et al.*, 2016; Ramya *et al.*, 2017). By integrating irradiation with OD, the reliance on thermal treatments is reduced, thereby maintaining the quality of the product and nutritional value (Asghari *et al.*, 2024; Ramya *et al.*, 2017). A study is being conducted on the combined effects of gamma irradiation and OD to determine the drying kinetics of dried potato and quality characteristics, namely its appearance, rehydration ratio, and vitamin C content (Rastogi and Raghavarao, 2004; Wang *et al.*, 2003). Researchers found that gamma radiation exposure causes (3.0–12.0 kGy) structural changes in tissues that increase cell permeability and thus maximize mass transfer rates (Nayak *et al.*, 2007). In a study by Srijaya and Shanthti (2017), it was reported that OD or gamma irradiation preserved guava slice nutrients and color during storage. Mousa *et al.* (2024) investigated the impact of OD with various treatment solutions (1% citric acid, 20% sucrose, and their combination) and gamma irradiation (1 and 3 kGy) on the nutritional quality of dried fruit. Their findings indicated that treating fruit with a combination of 1% citric acid and 20% sucrose before drying at 3 kGy improved its nutritional properties. However, sensory evaluation results showed that the sample irradiated at 1 kGy received higher ratings than the samples treated at 3 kGy. Hassan *et al.* (2024) evaluated the effects of various osmotic solutions (1% citric acid, 10% NaCl, and their combination) and gamma irradiation (1 and 3 kGy) on the quality of dehydrated vegetable slices. The results showed that pre-treatment with 1% citric acid and 10% NaCl enhanced ash content (3.43–4.34%), hardness,

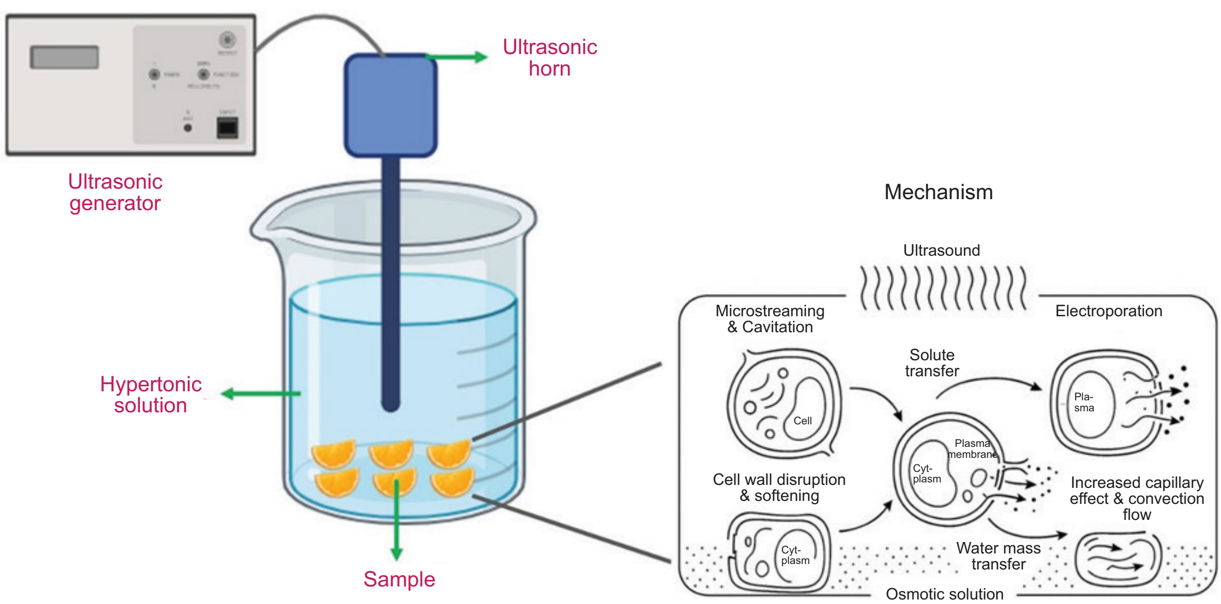

Figure 2. Ultrasound-assisted osmotic dehydration setup and mechanism showing enhanced mass transfer via cavitation, cell disruption, and electroporation.

Table 2. Effect of ultrasound-assisted osmotic dehydration treatment conditions on the quality parameters of different products.

Product	Osmotic agent	O/P ratio	Ultrasound conditions	Results	References
Persimmon	Sucrose solution (45 & 70°Brix)	-	35 kHz, 10–30 min	• Increased water loss and sugar gain • Decreased drying time and 21% increase in effective water diffusivity by 30 min	Bozkir *et al.*, 2019
Mango	Sucrose solutions (120–500 kg/m^3)	4:1	25 kHz, 55 kW/m^3	• Ultrasonic pretreatment only effective with 500 kg sucrose/m^3	Fernandes *et al.*, 2019
Chinese yam	Salt solution (5%)	-	1.52, 2.28, and 3.04 W/g	• Increased the mass transfer, increased loss factor, and made the water more mobile • Acceleration of drying and energy savings	Li *et al.*, 2020
Litchi	Sucrose solution (50%)	4:1	37 kHz	• Rise in water loss (28.73±3.25%) and solid gain (45.44±6.85%) levels in litchi fruit • Enhancement in fruit quality during freezing and thawing processes	Fong-in *et al.*, 2021
Peach	Sucrose solution (70%)	4:1	30 kHz, 100 W, 50 and 75% amplitude	• Remarkable reduction in microbial count and pathogen • Higher ultrasound amplitude boosts inactivation • Also reduced the moisture content, total phenolics, and DPPH antiradical activity	Hashemi and Jafarpour, 2021
Strawberry	Sucrose: 40-g/100 g solution Trehalose: 40-g/100 g solution Sucrose–maltodextrin solution: 30-g sucrose + 10-g maltodextrin per 100-g solution	4:1	45 Hz, 180–360 W	• Ultrasound treatment increases the drying rate and reduces drying time by 10% • Dried product has better texture and nutritional quality	Jiang *et al.*, 2021
Plum	Sucrose (20°Brix)	4:1	40 kHz, 0.45–1.35 W/g	• Improvement in mass transfer • Shortening of drying time • Lower ultrasound intensity can retain the quality better	Li *et al.*, 2021
Apple	Sucrose (30–50°Brix)	-	40 kHz, 75–150 W	• Higher concentrations of sucrose solution led to greater weight reduction, increased soluble solids gain, and enhanced water loss • Elevated sonication power levels contributed to increased weight reduction, higher soluble solids gain, and greater water loss	Salehi *et al.*, 2022
Gooseberry	Sugar solution (45–65%)	6:1–14:1	100–500 W	• Power level of 280 W proved effective for achieving higher water loss in gooseberry • Ultrasound treatment inactivates microorganisms and enzymes in cape gooseberry, thereby extending its shelf life • Optimal conditions for the process variables—ultrasonication power, time, solvent concentration, and solid-to-solvent ratio—were determined to be 282.434 W, 50.280 min, 55.836%, and 9.250 w/w, respectively	Kumar Dash *et al.*, 2023
Beetroot	Salt (NaCl) (0–30%)	-	40 kHz, 50–100 W	• The quality characteristics were preserved • Enhanced color observed with all pretreatments • Significantly higher DPPH scavenging activities after ultrasonic-assisted osmotic dehydration	Memis *et al.*, 2023
Kiwifruit	Sucrose solution (20%, 30%, and 40%)	-	40 kHz, 75 and 150 W	• UAOD treatment increased moisture loss and soluble solids gain • Higher ultrasound intensity (150 W) showed reduced duration of dehydration (higher water loss), improved dehydration rate, and increased effective moisture diffusivity	Salehi *et al.*, 2023

Note: O/P: osmotic agent–product mass ratio; DPPH: 2,2-diphenyl-1-picrylhydrazyl.

and total phenolic content (38.37–117.04 mg gallic acid equivalent [GAE]/100 g). Additionally, sensory evaluation indicated that samples irradiated at 1 kGy were rated higher in preference, compared to those exposed to 3 kGy or left unirradiated

Centrifugal osmotic dehydration technique

Fruit and vegetable processing industries are using centrifugal osmotic dehydration (COD) as a tool to increase mass fluxes during OD (Barman and Badwaik, 2017). Amami *et al.* (2007) suggested the use of centrifugal force during osmosis, resulting in a higher ratio between water loss and solute absorption. In the OD process using a salt solution, centrifugation of bamboo shoots led to an increased rehydration ratio, concurrently reducing solid gain, hardness, and color values (Badwaik *et al.*, 2014).

Microwave-assisted osmotic dehydration

The MW drying method is a relatively new mode to dry food. MWs are capable of penetrating food materials to generate heat within them. MW treatment induces a vapor pressure that expels moisture from the interior to the outer surface, simultaneously diminishing the rate of case hardening (Manzoor *et al.*, 2021). A distinctive characteristic of MW is its ability to generate internal heat within the product, a phenomenon known as volumetric heating (Surendhar *et al.*, 2019). The key differentiating characteristics of MW heating from conventional heating lie in the rate and direction of heat transfer. As electromagnetic fields are applied in MW drying, dielectric molecules are agitated, resulting in a rapid rise in temperature (Amanda *et al.*, 2021). A MW-assisted OD process uses electromagnetic radiation with a frequency of 2,450 MHz to enhance the removal of moisture from fruits or vegetables by allowing them to soak in a hypertonic solution of an osmotic agent (Figure 3). Similarly, the use of solutes, such as sugar or salt, offers benefits in minimizing the shrinkage of fruits. These solutions aid in penetrating the tissue, contributing favorably to the characteristics of the final product (Manzoor *et al.*, 2021).

Microwave-assisted osmo-dehydration, when compared to OD alone, results in more water loss to solid gain than OD alone. The application of MW power in conjunction with osmotic pressure results in the removal of moisture from agricultural produce. This process is influenced by the dielectric properties of the material and the concentration difference between the solvent and solute. Using a continuous medium flow in immersion and spray mode, Azarpazhooh and Ramaswamy (2010) preformed MW-assisted OD of apple slices. In addition to enhancing moisture loss, spray mode heating conditions also reduced solute uptake because the MW field was directly and effectively exposed to the sample. Additionally, the spray mode prevents fruit from floating in a large volume of an osmotic solution because the solution is applied to the sample in a thin layer, which can be applied continuously.

Owing to micro-surface cracks in the surface of the food, MW vacuum and OD can be used to preserve food with improved mass transfer and shorter drying period (Zielinska *et al.*, 2018). Furthermore, low processing temperatures prevent heat-labile components from degrading (Zielinska *et al.*, 2015). Researchers have documented enhancements in the quality of various fruits and vegetables, including apples, blueberries, strawberries, potatoes, tomatoes, and mushrooms, through the application of combined techniques involving MW vacuum and OD (Figiel and Michalska, 2017). By using OD with MW-vacuum drying, this technique is conducive to high-quality appearance, flavor retention, and absorption of high nutrients (Pandiselvam *et al.*, 2021).

Pulsed vacuum osmotic dehydration

Pulsed vacuum osmotic dehydration (PVOD) is identified as the most suitable and effective method for treating both animal and plant tissues. It facilitates rapid and controlled transfer of moisture and solute across the cell membrane (Figure 4; Araújo and Pena, 2023; Şahin and Öztürk, 2016). PVOD is a phenomenon primarily caused by hydrodynamic mechanism, in which foreign substances that have occupied capillary pores are expelled under atmospheric pressure of 0.005–0.04 MPa, while an osmotic solution diffuses into the pores caused by deformation and relaxation of the pores (Derossi *et al.*, 2010). Intercellular spaces are controlled by the presence of gases or liquids. By lowering the pressure, the gas or liquid inside capillary pores becomes occluded and escapes from the tissue. In a pressure-restored atmosphere, external solutions enter the pores, resulting in loss of moisture and accumulation of external solute (Araújo and Pena, 2023; Viana *et al.*, 2014).

A solution-to-fruit ratio, level of pressure, process temperature, concentration of osmotic media, and time of impregnation are important factors in PVOD. The geometrical shape of the sample, its viscoelastic properties, proximate constituents as well as the osmotic medium and relaxation time of the solid matrix are crucial factors that should be considered. These factors are interrelated with the mechanical characteristics of the matrix and play a significant role in the overall OD process (Corrêa *et al.*, 2015). Although mass transfer improves with an increased number of vacuum pulses, the duration required for impregnation is primarily influenced

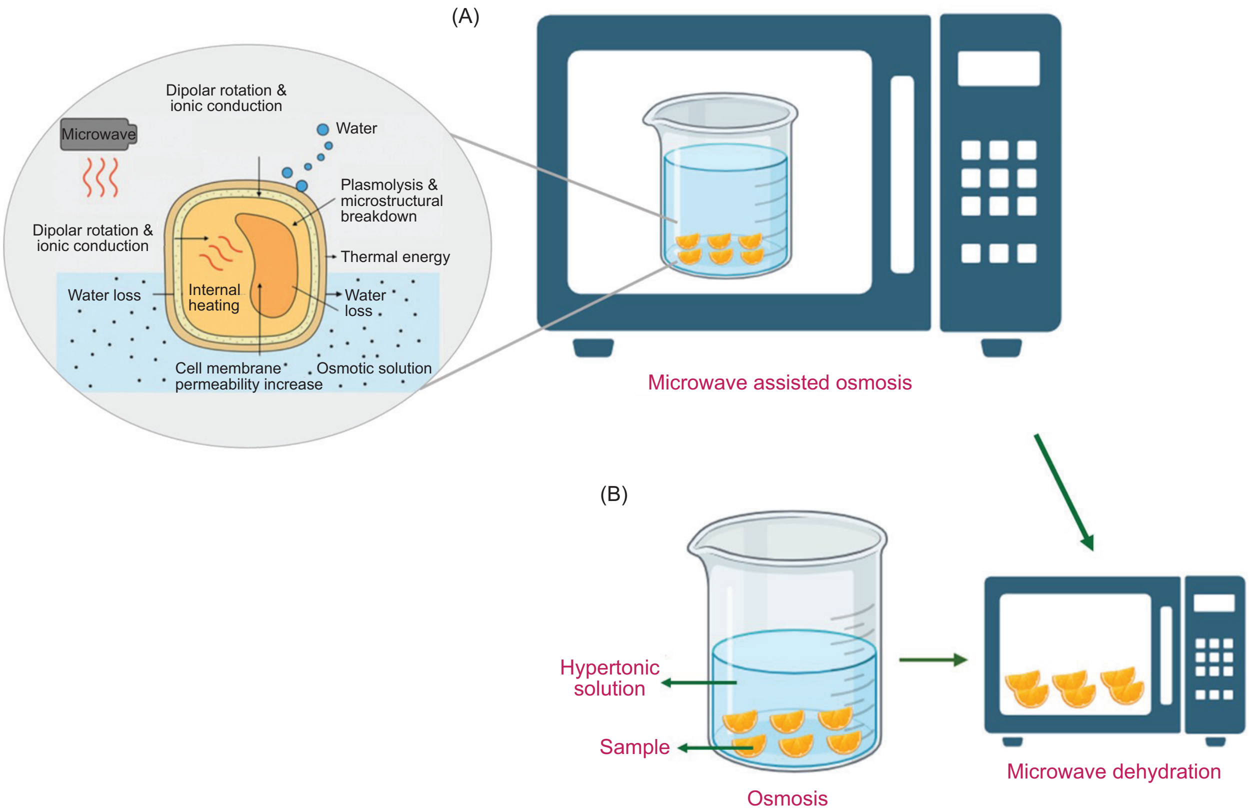

Figure 3. Microwave (MW)-assisted osmotic dehydration process: (A) MW-induced cell membrane permeability enhances water loss during osmosis, and (B) post-osmosis MW drying further removes moisture from the sample.

by the biological properties of the material (Sittiisuanjik *et al.*, 2021). In a study comparing the drying kinetics and quality of figs under PVOD, it proved to be more effective for water removal, shorter drying period, and preserving color, flavor, odor, and texture (Şahin and Öztürk, 2016). In contrast, de Jesus Junqueira *et al.* (2017) found that application of vacuum reduced betalain and phenolic compounds in carrot and eggplant, thereby causing significant changes in their optical, mechanical, and structural properties. Additionally, vacuum pressure is advantageous in OD because it speeds up the time of processing and allows for reduced energy consumption because of rapid mass transfer (Ghellam *et al.*, 2021). By excluding oxygen from the pores of fruits and vegetables, a great deal of discoloration is prevented (Haque *et al.*, 2020; Ramallo *et al.*, 2013).

Osmodehydro-Freezing (ODF) Technique

Research has shown that OD does not have the water-activity level necessary to produce a microbiologically stable product. Thus, it is imperative to use a complimentary processing technique, such as "air-drying" or "freezing," when trying to extend the shelf life (Alabi *et al.*, 2022). The process of partially/fractionally drying in a hypertonic solution, and then freezing the solution in a regular manner, is called osmodehydro-freezing (Giannakourou*et al.*, 2020). One of the most striking alternatives to conventional freezing, ODF has many advantages over the conventional process, especially in the case of fruits and vegetables that are adversely affected (Said *et al.*, 2015b). The freezing process, prior to or after dehydration, reduces the moisture available for quality degradation and minimizes unwanted physicochemical changes of food after thawing (Giannakourou *et al.*, 2020a).

Scientists have worked to develop ODF to preserve the quality of fruits and vegetables, as conventional freezing drying causes unwanted textural changes and softening (Sette *et al.*, 2016). Dehydrofrozen products are generally regarded as superior to conventionally frozen products and they are particularly suitable for goods with a high acidity content (Giannakourou *et al.*, 2020a). A key component of refining the quality of the product after freezing and thawing is the choice of an osmotic medium (Said *et al.*, 2015a, 2016).

Frozen vegetable if treated osmotically showed enhanced textural properties, such as reduced drip loss and crumbling (Ahmed *et al.*, 2016). Increase in glass

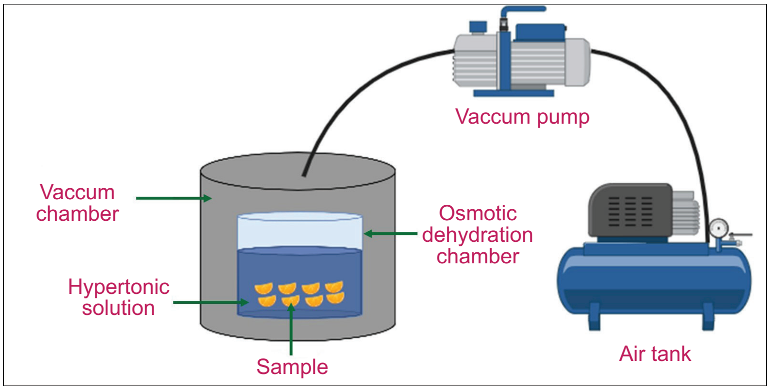

Figure 4. Schematic diagram of pulsed vacuum osmotic dehydration.

transition temperature during successive frozen storage is attributed to a decrease in moisture content along with solute impregnation (Zhao *et al.*, 2017). The application of OD can lead to reduced energy requirements for ice crystal formation. Additionally, it can contribute to decreased distribution and packaging costs (Lowithun and Charoenrein, 2009). Furthermore, the osmotic solution enhances both flow of water and solutes between food materials and heat transfer during freezing. According to Bchir *et al.* (2012), solid gain and water loss in dehydrated pomegranate seeds increased 3.5 and 1.4 times as much as in untreated samples. It is evident that it takes less time to dehydrofreeze the same product than it does to conventionally freeze the same product (Alharaty and Ramaswamy, 2023; Gülmez and Topuz, 2022). The results showed reduced freezing period of 20–30%, and even up to 50%, in comparison to the untreated products (Alabi *et al.*, 2022; Giannakourou *et al.*, 2020a; Lovera *et al.*, 2018; Zhao *et al.*, 2014).

Table 3 shows the effect of ODF treatment conditions on the quality parameters of different products. In a study conducted by Reyes-Alvarez and Lanari (2023), OD pretreatment enhanced the freezing rate by 58% and reduced drip loss in osmodehydro-frozen arazá by 40%. However, osmodehydrated samples exhibited the highest discoloration levels (15.7). Freezing and freeze-drying of pretreated OD arazá improved discoloration by 16–48%. While ODF increased total polyphenol bioaccessibility by 22% without affecting total flavonoid bioaccessibility, it led to a 16–42% reduction in antioxidant activity retention. In contrast, ODF drying negatively impacted all properties (13–55%), except for ferric-reducing antioxidant power (FRAP), which showed a 10% increase. In another investigation conducted by Dermesonlouoglou *et al.* (2024), pretreatment of OD effectively removed water, facilitated uptake of solids, and reduced water activity while preserving the key quality attributes of frozen cherry tomatoes. The optimal processing conditions were temperature of osmotic treatment = 36°C, time of osmotic treatment = 72 min, and concentration of glycerol = 61.5% w/w, determined based on achieving water loss (WL ≤ 5), color change (ΔE ≤ 8), and minimizing water activity at the end of pretreatment. Additionally,

Table 3. Effect of osmodehydro-freezing (ODF) treatment conditions on the quality parameters of different products.

Product	Osmotic reagant	O/P ratio	ODF conditions	Result	References
Arazá (*Eugenia stipitata* McVaugh)	Sucrose solution (60°Bx)	10:1	Precooled at 4°C for 12 h, then frozen using an air-blast tunnel at –30°C	• OD pretreatment increased freezing rate by 58% and reduced drip loss by 40%. • Osmodehydrated samples had the highest discoloration (15.7), but freezing/freeze-drying pretreated OD samples improved discoloration by 16–48%	Reyes-Alvarez and Lanari, 2023
Tomatoes	Solutions of 50–70% (w/w) glycerol, 3.5% NaCl, and 1.5% $CaCl_2$	5:1	Quickly frozen at –40°C	• OD-pretreated frozen cherry tomatoes showed reduced a_w (0.95–0.92), acceptable color, increased firmness, low drip loss, and high vitamin C/lycopene retention • OD may serve as a useful pre-processing step for delicate frozen fruits	Dermesonlouoglou *et al.*, 2024

Notes: OD: osmotic dehydration; a_w: water activity.

OD extended the shelf life of frozen cherry tomatoes by up to 3.5 times, as assessed by sensory quality retention.

High-pressure processing

High-pressure processing (HPP) is a nonthermal food preservation technique that involves subjecting liquid or solid foods, with or without packaging, to elevated pressures within the range of 50–1,000 MPa (Santos *et al.*, 2019; Serment-Moreno *et al.*, 2014). This method utilizes a combination of three key parameters: pressure, temperature, and time to achieve food preservation (Janowicz and Lenart, 2018). It requires no chemical preservatives and has the potential to destroy lethal microorganisms and enzymes at low temperatures, leading to less damage to low molecular compounds, such as flavoring agents, pigments, vitamins, etc. (Leite Júnior *et al.*, 2017; Matser and Vollebregt, 2017). Thus, better quality and sensory properties of food have made HPP a method of great interest (Houška *et al.*, 2022; Munir *et al.*, 2019).

The utilization of HPP alters the cell wall and tissue structure, leading to higher permeability of the cell (Srinivas *et al.*, 2018). Table 4 shows the effect of HPP on osmotic dried products. HPP improved mass transfer kinetics in Granny Smith apples, resulting in greater water loss and solid gain, compared to conventional OD (Dash and Balasubramaniam, 2018). This rapid dehydration, achieved within 15 min, demonstrated the potential of high-pressure technology for enhancing drying efficiency while preserving fruit quality. Sulistyawati *et al.* (2018) conducted a study that demonstrated that applying HPP before OD resulted in improved color retention in case of mango fruit. Further, Dash *et al.* (2019) noted that the application of high pressure during osmotic treatment significantly influenced the kinetics of water loss and solid gain in ginger slices. In another research conducted by Dermesonlouoglou *et al.* (2019), the combination of OD and HPP significantly improved microbial stability, prolonging the shelf life of peaches and apricots. Validated kinetic models indicated that OD/HP-treated peach and apricot spheres could be stored for 320 and 309 days at 4°C whereas fresh fruits typically last only 5–7 days. In comparison, OD-treated samples had a much shorter shelf life of 68–86 days at 4°C, primarily because of microbial growth. A study conducted by Luo *et al.* (2019) explored HPP as a pre-treatment for OD of wumei fruit, comparing it to traditional heating. Although, HPP did not significantly improve mass transfer, it elevated antioxidant content and enriched aromatic profile by boosting volatile compounds. With increasing pressure levels, there was a noticeable enhancement in the rate of moisture loss and solute uptake during the process of pressure-assisted OD. However, it's worth noting that using HPP at pressures exceeding 400 MPa can lead to the gelatinization of starch and impede the diffusion process (Balakrishna *et al.*, 2020).

Pulsed electric field

The PEF technique entails applying high-intensity short-duration electric pulses across the cell membrane, leading to breakage and formation of pores (Liu *et al.*, 2020; Ranjha *et al.*, 2021). Various mechanisms contribute to electrical breakage in PEF technique. These include reaching a critical trans-membrane potential, membrane compression, structural weaknesses in the cell membrane, and the viscoelastic properties of the membrane (Figure 5). When combined with OD, this treatment results in the structural disruption of the cell membrane, a process known as perforation, facilitating rapid mass flow (Jimah *et al.*, 2017).

Pulsed electric field treatment has demonstrated its potential to enhance food processing outcomes. It leads to increased permeability of plant cells, facilitating mass transfer without altering the product matrix (Parniakov *et al.*, 2016). Table 5 shows the effect of PEF on osmotic dried products. During OD of apple slices, the application of high-intensity electric field pulses as a pretreatment, as shown in the research conducted by Taiwo *et al.* (2003), had minimal effects on solids gain while improving color brightness, texture firmness, and the preservation of vitamin C content (Taiwo *et al.*, 2012). An optimal condition for PEF pre-treatment, using an electric field intensity of 5 kV/cm with 10 pulses, was identified in a study conducted by Wiktor *et al.* (2014). A comprehensive study conducted on the influence of PEF treatment on apples (Ciurzynska *et al.*, 2023) and carrots (Alam *et al.*, 2018) showed extensive browning in apple samples, probably resulting from oxidative reactions. In contrast, carrots displayed superior brightness, compared to control samples, possibly because of greater pigment leaching.

This study indicated that PEF pretreatment could lead to improved color characteristics (Zongo *et al.*, 2022). Additionally, Tylewicz *et al.* (2017) observed that the use of PEF treatment before OD was observed to have a favorable impact on mass transfer, specifically regarding water loss from strawberry tissue. Even when employing the lowest electric field intensity of 100 V cm^{-1}, there was a significant increase in water loss by 12% and 6% after 1 h of OD of strawberry in sucrose and trehalose solution, respectively. In another study, Yu *et al.* (2018) quoted that PFE pretreatment before OD yielded significantly improved dehydration results for blueberries, compared to both thermal pretreatment at 90°C and the control group. The inactivation of polyphenol oxidase during PEF pretreatment had a noteworthy impact, leading to enhanced retention of various compounds, including anthocyanins, predominantly

Table 4. Effect of high-pressure processing-assisted osmotic dehydration (HPP-OD) treatment conditions on the quality parameters of different products.

Product	Osmotic reagent	O/P ratio	HPP conditions	Result	References
Granny Smith apple	Fructose and sucrose solution (60°Brix)	4:1	200–600 MPa at 40°C	• Increased water loss and solid gain • Faster water removal within 15 min using high pressure	Dash and Balasubramaniam, 2018
Mango	60°Brix sucrose, 2 g calcium lactate/100 g, and 0 or 0.48 mL PME/100 g	4:1	300 MPa for 3–5 min	• Hue (h*) remained stable, while color intensity (C*) was maintained or slightly increased across treatments • Lightness (L*) decreased significantly in unripe mango but remained stable in ripe mango • Firmness and shear work slightly increased with PME addition	Sulistyawati *et al.*, 2018
Ginger	60°Brix solution of sucrose, fructose, and glucose	4:1	200–600 MPa at 40°C for hold period of 0.25, 2, 5, 10, and 15 min	• Higher pressure levels increased moisture loss and solute uptake • Glucose and fructose penetrated faster than sucrose in ginger slices • Glucose reduced water activity more effectively than fructose and sucrose	Dash *et al.*, 2019
Peach and apricot snacks	Concentrated solution containing: glycerol (50.0% w/w), erythritol (12.5% w/w), NaCl (3.5% w/w), calcium chloride (1.5% w/w), steviol glucosides (1.25% w/w), and Citrox© (0.2% w/w)	5:1	600 MPa at 25°C for 5 min	• Treated peaches and apricots had a shelf life of 320 days and 309 days, respectively, at 4°C, compared to fresh fruits which lasted for only 5–7 days under the same conditions	Dermesonlouoglou *et al.*, 2019
Wumei (*Prunus mume*)	Sucrose (40% w/w)	4:1	50 MPa for 1 min	• HPP significantly enhanced mass transfer, compared to heat treatment • Increased antioxidant content (ascorbic acid, phenols, flavonoids) and antioxidant activity • Improved aromatic profile with higher total and diverse volatile components	Luo *et al.*, 2019
Tomatoes	Medium contained: 10% w/w vinegar (8% acetic acid), 10% w/w maltodextrin (DE 47), 3.5% NaCl, and 1.5% calcium chloride and glycerol	5:1	100–600 MPa for 5 min	• Treatment at 600 MPa significantly restored firmness ($p < 0.05$), with complete PG inactivation while retaining PME activity • Water activity dropped below 0.90 in 40 min at 600 MPa, compared to 3+ h for untreated samples • OD duration for HPP-treated samples was reduced by half	Katsimichas *et al.*, 2023
Potatoes	Solution of 40% (wt) glycerol, 10% NaCl, and 1% ascorbic acid (AA) or 0.03% papain (P)	5:1	200–600 MPa	• HPP treatment enhanced solid gain more than water loss	Katsouli *et al.*, 2024

Notes: PME: pectin methylesterase; OD: osmotic dehydration; PG: polygalacturonase.

phenolic acids and flavonols, total phenolics, and antioxidant activity, in the dehydrated blueberries.

Ohmic heating

The synergistic application of ohmic heating and OD under atmospheric pressure accelerates mass transfer rates, particularly as the processing temperature rises (Kutlu, 2022). On the other hand, employing a comparable ohmic heating–osmotic technique under vacuum conditions at 50°C has proven to be a more effective method for dehydrating apples in a sucrose solution (Moreno *et al.*, 2013). The combination of ohmic pretreatment during OD under vacuum is highly efficient in extending the shelf life of apples to more than 4 weeks,

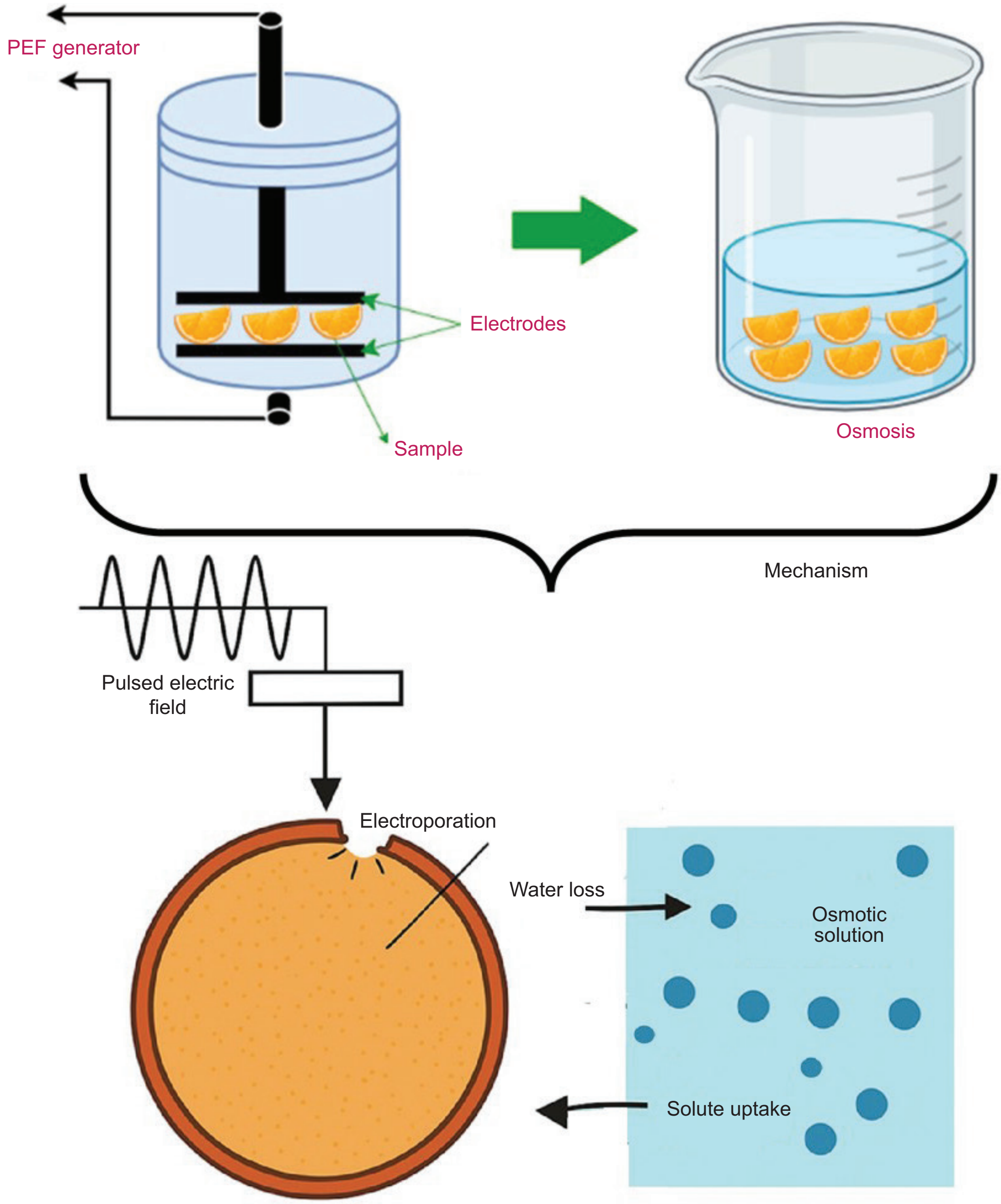

Figure 5. Pulsed electric field-assisted osmotic dehydration (PFE-OD) setup and mechanism illustrating electroporation-induced membrane permeability, enhancing water loss and solute uptake during osmosis.

as it completely inhibits polyphenol oxidase activity (Moreno *et al.*, 2013). The use of ohmic heating under vacuum also enhances the texture of the treated material by eliminating air from tissue pores and filling them with osmotic substances (Moreno *et al.*, 2012). In another study, Mercali *et al.* (2012) investigated the influence of ohmic and conventional heating treatments on the vitamin C content of acerola pulp. The results indicated that ohmic heating, particularly at low-voltage gradients, resulted in a decrease in ascorbic acid levels, mirroring the impact observed with conventional heating. On the other hand, the application of higher-voltage gradients accentuated reduction in ascorbic acid, primarily because of electrochemical reactions.

Use of an artificial and edible coating

The undesired uptake of solute in osmotically dehydrated products poses a limitation to the application of OD process. The increased solute content adds resistance to the mass transfer of water, resulting in a lower

Table 5. Effect of pulsed electric field-assisted osmotic dehydration (PFE-OD) treatment conditions on the quality parameters of different products.

Product	Osmotic agent	O/P ratio	PEF conditions	Results	References
Kiwifruit	Hypertonic sucrose or trehalose solution (40%, w/w)	4:1	100 and 200 V/cm, 100 Hz	• Higher dehydration takes place with trehalose • Cell viability was better preserved at 100 V/cm with trehalose than with sucrose • Kiwifruits retained firmness best at 100 V/cm with trehalose	Tylewicz *et al.*, 2019
Strawberry	Hypertonic sucrose or trehalose solution (40% w/w) 1% calcium lactate (CaLac) as a structuring agent	4:1	100 and 200 V/cm, frequency of 100 Hz	• The treatment resulted in lower levels of anthocyanins, compared to the untreated sample • Pulsed electric field (PEF) at 200 V/cm was identified as a promising and energy-efficient, mild processing technique for obtaining berry products with maintained anthocyanin content and higher stability during digestion	Oliveira *et al.*, 2019
	Hypertonic sucrose or trehalose solution (40% w/w)	4:1	100 and 200 V/cm, 100 Hz	• 100 V/cm electric field + OD increased dehydration, especially with trehalose • Cell viability was better preserved at 100 V/cm with trehalose than with sucrose • Strawberries performed better with OD treatment using sucrose for both electric fields	Tylewicz *et al.*, 2019
Sea bass fillets	50% glycerol (w/w) + 5% NaCl	5:1	1.6 kV/cm, 20 Hz	• PEF enhanced moisture loss during processing	Semenoglou *et al.*, 2020
Mango	Agave syrup (79% fructose, 20% glucose, and 1% sucrose) with addition of INU (5%) or INU (5%) + xanthan gum (0.3%)	100:1	kV/cm, 2 Hz	• PEF pretreatment led to a slight increase in water loss during osmotic dehydration, in contrast to freeze-thawing • Addition of xanthan gum to agave syrup solution reduced sugar uptake in frozen-thawed mangoes by increasing solution viscosity	Zongo *et al.*, 2022

dehydration rate during complementary drying. To address this issue, the use of an artificial and edible coating for food was explored as a novel approach to impede solute penetration without affecting the rate of water removal (Kowalska *et al.*, 2021). Edible films generally consist of four major types of materials: lipids–waxes–oils, resins, polysaccharides, and proteins (Kasai *et al.*, 2022; Priya *et al.*, 2023). The barrier properties of these coatings depend significantly on their composition and method of fabrication. When choosing an edible coating, the desired properties must include good mechanical strength (gel strength), satisfactory sensory attributes, resistance to microbial contamination and oxidation, easy and rapid film formation using simple techniques, high water diffusivity, and the ability to maintain the coating in an intact state without dissolving into osmotic solution. Additionally, the coating should impart greater aesthetic appeal, especially for products with clear polysaccharide coatings (Priya *et al.*, 2023).

In a separate study, García *et al.* (2010) examined the influence of chitosan coating on the OD of scale-cut papaya, revealing efficient water removal with minimal solute uptake, regardless of the ripening stage during osmotic process. Meanwhile, Jansrimanee and Lertworasirikul (2020) demonstrated that osmotically dried pumpkin samples coated with 3% sodium alginate (SA) exhibited higher values for water loss, reduced sugar content, and the ratio of water loss to reducing sugars, compared to alternative treatments. Alharaty and Ramaswamy (2020) reported that applying a sodium alginate–calcium chloride edible coating to fresh-cut strawberries significantly extended their refrigerated shelf life. The coated samples maintained mold-free quality for 15 days at 4°C, compared to just 7 days for uncoated controls. The coating effectively reduced respiration and transpiration rates while delaying increase in pH and content of soluble solids. Furthermore, the treatment preserved critical sensory attributes, including color and texture, demonstrating its potential for commercial fresh-cut fruit preservation applications. Additionally, Jalaee *et al.* (2011) examined the OD of apple rings coated with 92% carboxyl-methyl cellulose, observing a higher water loss-to-solute gain ratio along with improved texture.

Future Scope

A comprehensive examination of the microstructural impact of PEF and HPP treatments during OD on diverse food materials is imperative. While these emerging techniques show potential in enhancing mass transfer rates, their industrial-scale adoption remains a significant challenge, requiring focused efforts on process scale-up and optimization. Despite extensive research on osmotic concentration via membrane processes in the past, these endeavors fall short of rendering these industrially viable, thereby opening avenues for further research and development in this domain. The re-concentration of spent solution presently relies on conventional methods such as evaporation or solute addition. However, the adoption of membrane processes, such as reverse osmosis, membrane filtration, and ultrafiltration, holds considerable potential for exploration. Membrane-assisted OD addresses challenges associated with high solute concentration and microbial issues while sidestepping phase changes observed in evaporation. The integration of automatic control and online measurement, particularly when dealing with delicate materials, is crucial in designing effective equipment.

There exists ample room for exploration concerning the application of OD in diverse food products, including eggs and dairy items, as well as in non-food contexts. Globally, researchers are actively seeking modes to produce functional foods, necessitating the development of new technologies and equipment for manufacturing osmo-concentrated functional foods. In the processing of these functional foods, meticulous research is imperative to understand process parameters for the extraction or preservation of bioactive compounds. Given the scientific and industrial potential of OD, future researchers are anticipated to address these aspects. The objective of this article was poised to contribute to the identification of applications for OD across various sectors of the food and related industries in the forthcoming years.

Conclusions

The increasing awareness of consumer preferences for fresh food and the demand for sustainable food preservation methods have given rise to the practice of OD. In this process, moisture is partially removed across the cell membrane by applying high osmotic pressure using a hypertonic solution. Solute uptake and leaching of soluble solids during OD induce changes in product characteristics, leading to improvements in nutritional, functional, and organoleptic attributes. Osmotic dehydration offers several advantages, including the preservation of food properties, reduced thermal and oxidative damage, and lower energy costs.

The proportion of water removal and solid gain during OD is influenced by various factors, such as the variety, maturity level, and geometry of the food, as well as the use of pretreatments, temperature, concentration, and types of osmotic agents. To address the historically slow mass transfer proportion, various pretreatments, such as ohmic heating, PEF, MW, HPP, gamma irradiation, etc., are employed. Despite the promising features of OD, its industrial application is currently limited. Efforts are necessary to enhance the feasibility of this technology in the near future by addressing challenges related to solution management through the integration of newer technologies, particularly those involving membrane processes.

Data Availability Statement

All data used are presented in the manuscript.

Author Contributions

Kulwinder Kaur contributed equally to the conceptualization, original draft writing, and review and editing of the manuscript. Baldev Singh Kalsi was equally involved in data curation, original draft preparation, and manuscript review and editing. Ruchika Zalpouri played an equal role in project administration, drafting the original manuscript, and its subsequent review and editing. Pratik Pandit Potdar contributed equally to the formal analysis, original draft writing, and manuscript revision. Sajeev Rattan Sharma provided resources and supported the review and editing process. Mohammed Shafiq Alam supported the supervision of the project and contributed to the review and editing. Ravi Pandiselvam was equally involved in the review and editing of the manuscript.

Conflicts of Interest

The authors declared no conflict of interest.

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References

Abrahão, F.R. and Corrêa, J.L.G. 2023. Osmotic dehydration: more than water loss and solid gain. Critical Reviews in Food Science and Nutrition 63(17): 2970–2989. https://doi.org/10.1080/10408398.2021.1983764

Ahmed, I., Qazi, I.M. and Jamal, S. 2016. Developments in osmotic dehydration technique for the preservation of fruits and vegetables. Innovative Food Science and Emerging Technologies 34: 29–43. https://doi.org/10.1016/j.ifset.2016.01.003

Alabi, K.P., Olalusi, A.P., Olaniyan, A.M., Fadeyibi, A. and Gabriel, L.O. 2022. Effects of osmotic dehydration pretreatment on freezing characteristics and quality of frozen fruits and vegetables. Journal of Food Process Engineering 45(8): e14037. https://doi.org/10.1111/jfpe.14037

Alam, M.D.R., Lyng, J.G., Frontuto, D., Marra, F. and Cinquanta, L. 2018. Effect of pulsed electric field pretreatment on drying kinetics, color, and texture of parsnip and carrot. Journal of Food Science 83(8): 2159–2166. https://doi.org/10.1111/1750-3841.14216

Alharaty, G. and Ramaswamy, H.S. 2020. The effect of sodium alginate-calcium chloride coating on the quality parameters and shelf life of strawberry cut fruits. Journal of Composites Science 4(3): 123. https://doi.org/10.3390/jcs4030123

Alharaty, G. and Ramaswamy, H.S. 2023. Microwave-osmo-dehydro-freezing and storage of pineapple titbits—quality advantage. Processes 11(2): 494. https://doi.org/10.3390/pr11020494

Amami, E., Fersi, A., Vorobiev, E. and Kechaou, N. 2007. Osmotic dehydration of carrot tissue enhanced by pulsed electric field, salt and centrifugal force. Journal of Food Engineering 83(4): 605–613. https://doi.org/10.1016/j.jfoodeng.2007.04.021

Amanda, N., Shintya Kusuma Wardhani, N. and Ruspita Sari, A. 2021. Characteristics of several foodstuff drying by microwave: a review. In: Mizoguchi, M., Buerstmayr, H., Omar, R.C., Widodo, Tristan, A.C., and Shofiyati, I.R. (eds) Proceedings of the 2nd International Conference on Smart and Innovative Agriculture (ICoSIA 2021), Atlantis Press, Dordrecht, the Netherlands, pp. 296–301.

Araújo, A.L. de and Pena, R. da S. 2023. Combined pulsed vacuum osmotic dehydration and convective air-drying process of jambolan fruits. Foods 12(9): 1785. https://doi.org/10.3390/foods12091785

Asghari, A., Zongo, P.A., Osse, E.F., Aghajanzadeh, S., Raghavan, V., and Khalloufi, S. 2024. Review of osmotic dehydration: promising technologies for enhancing products' attributes, opportunities, and challenges for the food industries. Comprehensive Reviews in Food Science and Food Safety 23(3): e13346.

Azarpazhooh, E. and Ramaswamy, H.S. 2010. Microwave-osmotic dehydration of apples under continuous flow medium spray conditions: comparison with other methods. Drying Technology 28(1): 49–56. https://doi.org/10.1080/07373930903430611

Badwaik, L.S., Choudhury, M., Dash, K.K., Borah, P.K. and Deka, S.C. 2014. Osmotic dehydration of bamboo shoots enhanced by centrifugal force and pulsed vacuum using salt as osmotic agent. Journal of Food Processing and Preservation 38(5): 2069–2077. https://doi.org/10.1111/jfpp.12186

Balakrishna, A.K., Abdul Wazed, M., and Farid, M. 2020. A review on the effect of high pressure processing (HPP) on gelatinization and infusion of nutrients. Molecules 25(10): 2369. https://doi.org/10.3390/molecules25102369

Barba, C., Angós, I., Maté, J.I. and Cornejo, A. 2024. Effects of polyols at low concentration on the release of sweet aroma compounds in model soda beverages. Food Chemistry: X 22: 101440. https://doi.org/10.1016/j.fochx.2024.101440

Barman, N. and Badwaik, L.S. 2017. Effect of ultrasound and centrifugal force on carambola (*Averrhoa carambola* L.) slices during osmotic dehydration. Ultrasonics Sonochemistry 34: 37–44. https://doi.org/10.1016/j.ultsonch.2016.05.014

Barrera, C., Betoret, N. and Seguí, L. 2024. Potential of vacuum impregnation and osmotic dehydration techniques in producing jaggery-fortified apple snacks. Sustainable Food Technology 2(4): 1041–1051. https://doi.org/10.1039/d3fb00255a

Bashir, N., Sood, M. and Bandral, J.D. 2020. Food preservation by osmotic dehydration—a review. Chemical Science Review and Letters 9: 337–341. https://doi.org/10.37273/chesci.CS20510178

Bchir, B., Besbes, S., Attia, H. and Blecker, C. 2012. Osmotic dehydration of pomegranate seeds (*Punica granatum* L.): effect of freezing pre-treatment. Journal of Food Process Engineering 35(3): 335–354. https://doi.org/10.1111/j.1745-4530.2010.00591.x

Bellary, A.N., Indiramma, A.R., Prakash, M., Baskaran, R. and Rastogi, N. K. 2016. Anthocyanin infused watermelon rind and its stability during storage. Innovative Food Science and Emerging Technologies 33: 554–562. https://doi.org/10.1016/j.ifset.2015.10.010

Borse, S.M., Singh, M., Kaur, P., Singh, S. and Zalpouri, R. 2024. Drying behavior and nutritional quality of bitter-gourd slices dried in a solar dryer with tray and skewer arrangement. Environmental Progress and Sustainable Energy 43(5): e14445. https://doi.org/10.1002/ep.14445

Bozkir, H., Rayman Ergün, A., Serdar, E., Metin, G. and Baysal, T. 2019. Influence of ultrasound and osmotic dehydration pretreatments on drying and quality properties of persimmon fruit. Ultrasonics Sonochemistry 54: 135–141. https://doi.org/10.1016/J.ULTSONCH.2019.02.006

Brochier, B., Inácio, J.M. and Noreña, C.P.Z. 2019. Study of osmotic dehydration of kiwi fruit using sucrose solution. Brazilian Journal of Food Technology 22: e2018146. https://doi.org/10.1590/1981-6723.14618

Chambi, H.N.M., Lima, W.C.V. and Schmidt, F.L. 2016. Osmotic dehydration of yellow melon using red grape juice concentrate. Food Science and Technology (Brazil) 36(3): 468–475. https://doi.org/10.1590/1678-457X.01416

Chavan, U.D. and Amarowicz, R. 2012. Osmotic dehydration process for preservation of fruits and vegetables. Journal of Food Research 1(2): 202–209. https://doi.org/10.5539/jfr.v1n2p202

Cichowska, J., Żubernik, J., Czyżewski, J., Kowalska, H. and Witrowa-Rajchert, D. 2018. Efficiency of osmotic dehydration of apples in polyols solutions. Molecules 23(2): 446. https://doi.org/10.3390/molecules23020446

Ciurzyńska, A., Kowalska, H., Czajkowska, K. and Lenart, A. 2016. Osmotic dehydration in production of sustainable and healthy food. Trends in Food Science & Technology 50: 186–192. https://doi.org/10.1016/J.TIFS.2016.01.017

Ciurzynska, A., Trusinska, M., Rybak, K., Wiktor, A. and Nowacka, M. 2023. The influence of pulsed electric field and air temperature on the course of hot-air drying and the bioactive compounds of apple tissue. Molecules 28(7): 2970. https://doi.org/10.3390/molecules28072970

Corrêa, J.L.G., Dantas Viana, A., Soares de Mendonça, K. and Justus, A. 2015. Optimization of pulsed vacuum osmotic dehydration of sliced tomato. In: Delgado, J., and Lima, A.B. de (eds) Drying and Energy Technologies. Springer, New York, NY, pp. 207–228.

Corrêa, J.L.G., Lopes, F.J., de Mello Junior, R.E., de Jesus Junqueira, J.R., de Angelis Pereira, M.C. and Salvio, L.G.A. 2021. Dried yacon with high fructo oligosaccharide content. Journal of Food Process Engineering 44: e13884. https://doi.org/10.1111/jfpe.13884

Cozma, A.I. and Sievenpiper, J.L. 2014. The role of fructose, sucrose and high-fructose corn syrup in diabetes. European Endocrinology 10(1): 51–60. https://doi.org/10.17925/ee.2014.10.01.51

Cruz, M. de S., Corrêa, J.L.G., Macedo, L.L., Nascimento, B. de S., Santos, A.A. de L., Machado, G.G.L., Silveira, P.G. and Oliveira, C.R. de. 2025. Use of ethanol in convective drying of coated and osmotically dehydrated papaya with isomaltulose. Food and Bioprocess Technology 18: 4048-4066. https://doi.org/10.1007/s11947-024-03724-2

Dash, K.K. and Balasubramaniam, V.M. 2018. Effect of high pressure on mass transfer kinetics of granny smith apple. Drying Technology 36(13): 1631–1641. https://doi.org/10.1080/07373937.2017.1421218

Dash, K.K., Balasubramaniam, V.M. and Kamat, S. 2019. High pressure assisted osmotic dehydrated ginger slices. Journal of Food Engineering 247: 19–29. https://doi.org/10.1016/j.jfoodeng.2018.11.024

de Jesus Junqueira, J.R., Corrêa, J.L.G., Mendonça, K.S. de, Resende, N.S. and Barros Vilas Boas, E.V. de 2017. Influence of sodium replacement and vacuum pulse on the osmotic dehydration of eggplant slices. Innovative Food Science and Emerging Technologies 41: 10–18. https://doi.org/10.1016/j.ifset.2017.01.006

Delfiya, D.S.A., Prashob, K., Murali, S., Alfiya, P.V, Samuel, M.P. and Pandiselvam, R. 2022. Drying kinetics of food materials in infrared radiation drying: a review. Journal of Food Process Engineering 45(6), e13810. https://doi.org/10.1111/jfpe.13810

Dermesonlouoglou, E.K., Angelikaki, F., Giannakourou, M.C., Katsaros, G.J. and Taoukis, P.S. 2019. Minimally processed fresh-cut peach and apricot snacks of extended shelf-life by combined osmotic and high pressure processing. Food and Bioprocess Technology 12(3): 371–386. https://doi.org/10.1007/s11947-018-2215-1

Dermesonlouoglou, E., Pittas, L., Taoukis, P. and Giannakourou, M. 2024. Osmo dehydrofreezing of tomatoes: optimization of osmotic dehydration and shelf life modeling. Foods 13(17): 2689. https://doi.org/10.3390/foods13172689

Derossi, A., Pilli, T. De and Severini, C. 2010. Reduction in the pH of vegetables by vacuum impregnation: a study on pepper. Journal of Food Engineering 99(1): 9–15. https://doi.org/10.1016/j.jfoodeng.2010.01.019

Ding, S. and Yang, J. 2021. The effects of sugar alcohols on rheological properties, functionalities, and texture in baked products—a review. Trends in Food Science and Technology 111: 670–679. https://doi.org/10.1016/j.tifs.2021.03.009

Fernandes, F.A.N., Braga, T.R., Silva, E.O. and Rodrigues, S. 2019. Use of ultrasound for dehydration of mangoes (*Mangifera Indica* L.): kinetic modeling of ultrasound-assisted osmotic dehydration and convective air-drying. Journal of Food Science and Technology 56(4): 1793–1800. https://doi.org/10.1007/s13197-019-03622-y

Figiel, A. and Michalska, A. 2017. Overall quality of fruits and vegetables products affected by the drying processes with the assistance of vacuum-microwaves. International Journal of Molecular Sciences 18(1): 71. https://doi.org/10.3390/ijms18010071

Fong-in, S., Nimitkeatkai, H., Prommajak, T. and Nowacka, M. 2021. Ultrasound-assisted osmotic dehydration of litchi: effect of pretreatment on mass transfer and quality attributes during frozen storage. Journal of Food Measurement and Characterization 15(4): 3590–3597. https://doi.org/10.1007/s11694-021-00931-9

García, M., Díaz, R., Martínez, Y. and Casariego, A. 2010. Effects of chitosan coating on mass transfer during osmotic dehydration of papaya. Food Research International 43(6): 1656–1660. https://doi.org/10.1016/j.foodres.2010.05.002

Ghellam, M., Zannou, O., Galanakis, C.M., Aldawoud, T.M.S., Ibrahim, S.A. and Koca, I. 2021. Vacuum-assisted osmotic dehydration of autumn olive berries: modeling of mass transfer kinetics and quality assessment. Foods 10(10): 2286. https://doi.org/10.3390/foods10102286

Giannakourou, M.C., Dermesonlouoglou, E.K., and Taoukis, P.S. 2020a. Osmodehydrofreezing: an integrated process for food preservation during frozen storage. Foods 9(8): 1042. https://doi.org/10.3390/foods9081042

Giannakourou, M.C., Lazou, A.E. and Dermesonlouoglou, E.K. 2020b. Optimization of osmotic dehydration of tomatoes in solutions of non-conventional sweeteners by response surface methodology and desirability approach. Foods 9(10): 1393. https://doi.org/10.3390/foods9101393

Gülmez, H.B. and Topuz, A. 2022. Effect of osmo- and convective dehydrofreezing on energy efficiency and some physicochemical properties of frozen red pepper. Akademik Gida 20(2): 103–113. https://doi.org/10.24323/akademik-gida.1149718

Haneef, N., Hanif, N., Hanif, T., Raghavan, V., Garièpy, Y. and Wang, J. 2024. Food fortification potential of osmotic dehydration and the impact of osmo-combined techniques on bioactive component saturation in fruits and vegetables. Brazilian Journal of Food Technology 27: e2023028. https://doi.org/10.1590/1981-6723.02823

Haque, M.R., Hosain, M.M., Rahman, M.A., Kamal, M.M., Mondal, S.C. and Islam, A.K.M.M. 2020. Modeling and optimization of the pulsed vacuum osmotic dehydration (PVOD) process of carrots in a ternary solution by response surface methodology. Journal of Microbiology, Biotechnology and Food Sciences 10(3): 454–460. https://doi.org/10.15414/jmbfs.2020.10.3.454-460

Hashemi, S.M.B. and Jafarpour, D. 2021. Antimicrobial and antioxidant properties of saturn peach subjected to ultrasound-assisted osmotic dehydration. Journal of Food Measurement and Characterization 15(3): 2516–2523. https://doi.org/10.1007/s11694-021-00842-9

Hassan, N.A.A., Mousa, E.A.M., Elbassiony, K.R.A. and Ali, M.I.K. 2024. Effect of osmotic dehydration and gamma irradiation on quality characteristics of dried vegetable slices. Journal of Food Measurement and Characterization 18: 9181–9194. https://doi.org/10.1007/s11694-024-02869-0

Hawa, L.C., Khoirunnida, F.L., and Sumarlan, S.H. 2020. Drying kinetics and physical changes of osmotically pretreated potato (*Solanum tuberosum* L.) slice. IOP Conference Series: Earth and Environmental Science 475: 012007. https://doi.org/10.1088/1755-1315/475/1/012007

Houška, M., Silva, F.V.M., Evelyn, Donsì, F., Ramirez, R., Buckow, R., Terefe, N.S. and Tonello, C. 2022. High pressure processing applications in plant foods. Foods 11(2): 223. https://doi.org/10.3390/foods11020223

Jalaee, F., Fazeli, A., Fatemian, H. and Tavakolipour, H. 2011. Mass transfer coefficient and the characteristics of coated apples in osmotic dehydrating. Food and Bioproducts Processing 89(4): 367–374. https://doi.org/10.1016/j.fbp.2010.09.012

Janowicz, M. and Lenart, A. 2018. The impact of high pressure and drying processing on internal structure and quality of fruit. European Food Research and Technology 244: 1329-1340. https://doi.org/10.1007/s00217-018-3047-y

Jansrimanee, S. and Lertworasirikul, S. 2020. Synergetic effects of ultrasound and sodium alginate coating on mass transfer and qualities of osmotic dehydrated pumpkin. Ultrasonics Sonochemistry 69: 105256. https://doi.org/10.1016/j.ultsonch.2020.105256

Jeevarathinam, G., Pandiselvam, R., Pandiarajan, T., Preetha, P., Balakrishnan, M., Thirupathi, V. and Kothakota, A. 2021. Infrared-assisted hot air dryer for turmeric slices: effect on drying rate and quality parameters. Food Science and Technology (LWT) 144: 111258. https://doi.org/10.1016/J.LWT.2021.111258

Jiang, J., Zhang, M., Devahastin, S. and Yu, D. 2021. Effect of ultrasound-assisted osmotic dehydration pretreatments on drying and quality characteristics of pulsed fluidized bed microwave freeze-dried strawberries. Food Science and Technology (LWT) 145: 111300. https://doi.org/10.1016/j.lwt.2021.111300

Jimah, J., Schlesinger, P. and Tolia, N. 2017. Membrane lipid screen to identify molecular targets of biomolecules. Bio-protocol 7(15): e2427. https://doi.org/10.21769/bioprotoc.2427

Jiménez, N., Bassama, J., Soto, M., Dornier, M., Pérez, A.M., Vaillant, F. and Bohuon, P. 2020. Coupling osmotic dehydration with heat treatment for green papaya impregnated with blackberry juice solution. International Journal of Food Science & Technology 55(6): 2551–2561. https://doi.org/10.1111/ijfs.14507

Kalsi, B.S., Singh, S. and Alam, M.S. 2022. Influence of ultrasound processing on the quality of guava juice. Journal of Food Process Engineering 46(6): e14163. https://doi.org/10.1111/jfpe.14163

Kalsi, B.S., Singh, S., Alam, M.S. and Bhatia, S. 2023. Application of thermosonication for guava juice processing: impacts on bioactive, microbial, enzymatic and quality attributes. Ultrasonics Sonochemistry 99: 106595. https://doi.org/10.1016/j.ultsonch.2023.106595

Kasai, D.R., Radhika, D., Chalannavar, R.K., Chougale, R.B. and Mudigoudar, B. 2022. A study on edible polymer films for food packaging industry: current scenario and advancements. In: Dutta, A.K. and Ali, H.M. (eds) Advances in Rheology of Materials. IntechOpen. https://doi.org/10.5772/intechopen.107997

Katsimichas, A., Dimopoulos, G., Dermesonlouoglou, E. and Taoukis, P. 2023. Modelling and evaluation of the effect of pulsed electric fields and high pressure processing conditions on the quality parameters of osmotically dehydrated tomatoes. Applied Sciences (Switzerland) 13(20): 11397. https://doi.org/10.3390/app132011397

Katsoufi, S., Lazou, A.E., Giannakourou, M.C. and Krokida, M.K. 2017. Mass transfer kinetics and quality attributes of osmo-dehydrated candied pumpkins using nutritious sweeteners. Journal of Food Science and Technology 54(10): 3338–3348. https://doi.org/10.1007/s13197-017-2786-2

Katsouli, M., Dermesonlouoglou, E., Dimopoulos, G., Karafantalou, E., Giannakourou, M. and Taoukis, P. 2024. Shelf-Life Enhancement Applying Pulsed Electric Field and High-Pressure Treatments Prior to Osmotic Dehydration of Fresh-Cut Potatoes. Foods 13(1):171. https://doi.org/10.3390/foods13010171

Kaur, D. 2022. Osmo-Assisted Convective and Solar Drying of Papaya Cubes Using Different Natural Sweeteners. Punjab Agricultural University, Ludhiana, Punjab, India.

Kaur, K. and Singh, A.K. 2016. Effect of packaging material and storage conditions on quality of beetroot powder. Agricultural Research Journal 53(3): 400. https://doi.org/10.5958/2395-146x.2016.00076.4

Kaur, S., Singh, M., Zalpouri, R. and Kaur, K. 2023. Potential application of domestic solar dryers for coriander leaves: drying kinetics. Thermal Efficiency, and Quality Assessment, Environmental Progress & Sustainable Energy 42(4): e14092. https://doi.org/10.1002/ep.14092

Kaur, D., Singh, M., Zalpouri, R., Kaur, P. and Gill, R.S. 2024. Enhancing physicochemical properties of papaya through osmotic dehydration with various natural sweeteners. Scientific Reports 14(1): 23797. https://doi.org/10.1038/s41598-024-74605-z

Kaur, D., Singh, M., Zalpouri, R. and Singh, I. 2022. Osmotic dehydration of fruits using unconventional natural sweeteners and non-thermal-assisted technologies: a review. Journal of Food Processing and Preservation 46(12): e16890. https://doi.org/10.1111/jfpp.16890

Kaur, P., Zalpouri, R., Singh, M. and Verma, S. 2020. Process optimization for dehydration of shelled peas by osmosis and three-stage convective drying for enhanced quality. Journal of Food Processing and Preservation 44(12): e14983. https://doi.org/10.1111/jfpp.14983

Kowalska, H., Marzec, A., Domian, E., Kowalska, J., Ciurzyńska, A. and Galus, S. 2021. Edible coatings as osmotic dehydration pretreatment in nutrient-enhanced fruit or vegetable snacks development: a review. Comprehensive Reviews in Food Science and Food Safety 20(6): 5641–5674. https://doi.org/10.1111/1541-4337.12837

Kowalska, H., Trusinska, M., Rybak, K., Wiktor, A., Witrowa-Rajchert, D. and Nowacka, M. 2023. Shaping the properties of osmo-dehydrated strawberries in fruit juice concentrates. Applied Sciences (Switzerland) 13(4): 2728. https://doi.org/10.3390/app13042728

Kumar, C., Singh, M., Zalpouri, R., and Kaur, P. 2023. An in-depth analysis of various technologies used for mushroom drying. Food Engineering Reviews 15: 491–524. https://doi.org/10.1007/s12393-023-09351-5

Kumar Dash, K., Sundarsingh, A., Bhagya Raj, G.V.S., Kumar Pandey, V., Kovács, B. and Mukarram, S.A. 2023. Modelling of ultrasonic assisted osmotic dehydration of cape gooseberry using adaptive neuro-fuzzy inference system (ANFIS). Ultrasonics Sonochemistry 96: 106425. https://doi.org/10.1016/j.ultsonch.2023.106425

Kutlu, N. 2022. Optimization of ohmic heating-assisted osmotic dehydration as a pretreatment for microwave drying of quince. Food Science and Technology International 28(1): 60–71. https://doi.org/10.1177/1082013221991613

Kutlu, N., Pandiselvam, R., Saka, I., Kamiloglu, A., Sahni, P. and Kothakota, A. 2022. Impact of different microwave treatments on food texture. Journal of Texture Studies 53(6): 709–736. https://doi.org/10.1111/jtxs.12635

Lazou, A., Dermesonlouoglou, E.K. and Giannakourou, M.C. 2020. Modeling and evaluation of the osmotic pretreatment of tomatoes (*S. Lycopersicum*) with alternative sweeteners for the production of candied products. Food and Bioprocess Technology 13(6): 948–961. https://doi.org/10.1007/s11947-020-02456-3

Lech, K., Figiel, A., Michalska, A., Wojdylo, A. and Nowicka, P. 2020. The effect of selected fruit juice concentrates used as osmotic agents on the drying kinetics and chemical properties of vacuum-microwave drying of pumpkin. Journal of Food Quality 2018 (1): 7293932. https://doi.org/10.1155/2018/7293932

Leite Júnior, B.R. de C., Tribst, A.A.L. and Cristianini, M. 2017. Effect of high-pressure technologies on enzymes applied in food processing. In: Şentürk, M. (eds) Enzyme Inhibitors and Activators. InTech. https://doi.org/10.5772/66629

Li, L., Yu, Y., Xu, Y., Wu, J., Yu, Y., Peng, J., An, K., Zou, B. and Yang, W. 2021. Effect of ultrasound-assisted osmotic dehydration pretreatment on the drying characteristics and quality properties of sanhua plum (*Prunus salicina* L.). Food Science and Technology (LWT) 138: 110653. https://doi.org/10.1016/j.lwt.2020.110653

Li, L., Zhang, M. and Wang, W. 2020. Ultrasound-assisted osmotic dehydration pretreatment before pulsed fluidized bed microwave freeze-drying (PFBMFD) of Chinese Yam. Food Bioscience 35: 100548. https://doi.org/10.1016/j.fbio.2020.100548

Liu, C., Pirozzi, A., Ferrari, G., Vorobiev, E. and Grimi, N. 2020. Impact of pulsed electric fields on vacuum drying kinetics and physicochemical properties of carrot. Food Research International 137: 109658. https://doi.org/10.1016/J.FOODRES.2020.109658

Lovera, N.N., Ramallo, L. and Salvadori, V.O. 2018. Effects of different freezing methods on calcium-enriched papaya (*Carica Papaya* L.). Journal of Food Science and Technology 55(6): 2039–2047. https://doi.org/10.1007/s13197-018-3118-x

Lowithun, N. and Charoenrein, S. 2009. Influence of osmodehydrofreezing with different sugars on the quality of frozen rambutan. International Journal of Food Science & Technology 44(11): 2183–2188. https://doi.org/10.1111/j.1365-2621.2009.02058.x

Luo, W., Tappi, S., Wang, C., Yu, Y., Zhu, S., Dalla Rosa, M. and Rocculi, P. 2019. Effect of high hydrostatic pressure (HHP) on the antioxidant and volatile properties of candied wumei fruit (*Prunus mume*) during osmotic dehydration. Food and Bioprocess Technology 12(1): 98–109. https://doi.org/10.1007/s11947-018-2196-0

Macedo, L.L., Corrêa, J.L.G., Araújo, C. da S., Oliveira, D. da S. and Teixeira, L.J.Q. 2023. Use of coconut sugar as an alternative agent in osmotic dehydration of strawberries. Journal of Food Science 88(9): 3786–3806. https://doi.org/10.1111/1750-3841.16715

Mahesh, U., Mishra, S. and Mishra, H. 2017. Standardization of honey and sugar solution of osmotic dehydration of pineapple (*Ananas Comosus* L.) fruit slices. International Journal of Current Microbiology and Applied Sciences 6(7): 2364–2370. https://doi.org/10.20546/ijcmas.2017.607.280

Manzoor, A., Jan, B., Rizvi, Q.U.E.H., Junaid, P.M., Pandith, J.A., Dar, I.H., Bhat, S.A. and Ahmad, S. 2023. Osmotic dehydration technology for preservation of fruits and vegetables. In: Goyal, M.R. and Ahmad, F. (eds) Quality Control in Fruit and Vegetable Processing, Apple. Academic Press, Cambridge, MA, pp. 167–184. https://doi.org/10.1201/9781003304999-9

Manzoor, A., Khan, M.A., Mujeebu, M.A. and Shiekh, R.A. 2021. Comparative study of microwave assisted and conventional osmotic dehydration of apple cubes at a constant temperature. Journal of Agriculture and Food Research 5: 100176. https://doi.org/10.1016/j.jafr.2021.100176

Mari, A., Parisouli, D.N. and Krokida, M. 2024. Exploring osmotic dehydration for food preservation: methods, modelling, and modern applications. Foods 13(17): 2783. https://doi.org/10.3390/foods13172783

Matser, A. and Vollebregt, M. 2017. High-pressure processing combined with heat for fruit and vegetable preservation. In: Houška, M. and da Silva, F.V.M. (eds) High Pressure Processing of Fruit and Vegetable Products, pp. 135–145. https://doi.org/10.1201/9781315121123

Memis, H., Bekar, F., Guler, C., Kamiloğlu, A. and Kutlu, N. 2023. Optimization of ultrasonic-assisted osmotic dehydration as a pretreatment for microwave drying of beetroot (*Beta vulgaris*). Food Science and Technology International 30(5): 439–449. https://doi.org/10.1177/10820132231153501

Mendonça, K., Correa, J., Junqueira, J., Angelis-Pereira, M. and Cirillo, M. 2017. Mass transfer kinetics of the osmotic dehydration of yacon slices with polyols. Journal of Food Processing and Preservation 41: e12983. https://doi.org/10.1111/jfpp.12983

Mercali, G.D., Jaeschke, D.P., Tessaro, I.C. and Marczak, L.D.F. 2012. Study of vitamin C degradation in acerola pulp during ohmic and conventional heat treatment. Food Science and Technology (LWT) 47(1): 91–95. https://doi.org/10.1016/j.lwt.2011.12.030

Moreno, J., Simpson, R., Pizarro, N., Parada, K., Pinilla, N., Reyes, J.E., and Almonacid, S. 2012. Effect of ohmic heating and vacuum impregnation on the quality and microbial stability of osmotically dehydrated strawberries (Cv. Camarosa). Journal of Food Engineering 110(2): 310–316. https://doi.org/10.1016/j.jfoodeng.2011.03.005

Moreno, J., Simpson, R., Pizarro, N., Pavez, C., Dorvil, F., Petzold, G. and Bugueño, G. 2013. Influence of ohmic heating/osmotic dehydration treatments on polyphenoloxidase inactivation. Physical Properties and Microbial Stability of Apples (Cv. Granny Smith). Innovative Food Science and Emerging Technologies 20: 198–207. https://doi.org/10.1016/j.ifset.2013.06.006

Mousa, E., Ali, M., Hassan, N. and Elbassiony, K. 2024. Effect of osmo-dehydration and gamma irradiation on nutritional characteristics of dried fruit. Egyptian Journal of Food Science 52(1): 1–16. https://doi.org/10.21608/ejfs.2024.263040.1174

Munir, M., Nadeem, M., Qureshi, T.M., Leong, T.S.H., Gamlath, C.J., Martin, G.J.O. and Ashok Kumar, M. 2019. Effects of high pressure, microwave and ultrasound processing on proteins and enzyme activity in dairy systems—a review. Innovative Food Science and Emerging Technologies 57: 102192. https://doi.org/10.1016/j.ifset.2019.102192

Nayak, C.A., Suguna, K., Narasimhamurthy, K. and Rastogi, N.K. 2007. Effect of gamma irradiation on histological and textural properties of carrot, potato and beetroot. Journal of Food Engineering 79(3): 765–770. https://doi.org/10.1016/j.jfoodeng.2006.02.040

Nowacka, M., Tylewicz, U., Romani, S., Dalla Rosa, M. and Witrowa-Rajchert, D. 2017. Influence of ultrasound-assisted osmotic dehydration on the main quality parameters of kiwifruit. Innovative Food Science & Emerging Technologies 41: 71–78. https://doi.org/10.1016/J.IFSET.2017.02.002

Nowacka, M., Dadan, M., and Tylewicz, U. 2021. Current applications of ultrasound in fruit and vegetables osmotic dehydration processes. Applied Sciences (Switzerland) 11(3): 1269. https://doi.org/10.3390/app11031269

Oliveira, G., Tylewicz, U., Dalla Rosa, M., Andlid, T. and Alminger, M. 2019. Effects of pulsed electric field-assisted osmotic dehydration and edible coating on the recovery of anthocyanins from in vitro digested berries. Foods 8(10): 505. https://doi.org/10.3390/foods8100505

Osae, R., Zhou, C., Xu, B., Tchabo, W., Tahir, H.E., Mustapha, A.T. and Ma, H. 2019. Effects of ultrasound, osmotic dehydration, and osmosonication pretreatments on bioactive compounds, chemical characterization, enzyme inactivation, color, and antioxidant activity of dried ginger slices. Journal of Food Biochemistry 43(5): e12832. https://doi.org/10.1111/jfbc.12832

Palacios Romero, I., Rodríguez Gómez, M.J., Sánchez Iñiguez, F.M. and Calvo Magro, P. 2022. Optimization of the osmotic dehydration process of plums (*Prunus salicina* Lindl.) in solutions enriched with inulin, using response surface methodology. Food Science and Technology (LWT) 157: 113092. https://doi.org/10.1016/j.lwt.2022.113092

Pandiselvam, R., Tak, Y., Olum, E., Sujayasree, O.J., Tekgül, Y., Çalışkan Koç, G., Kaur, M., Nayi, P., Kothakota, A. and Kumar, M. 2021. Advanced osmotic dehydration techniques combined with emerging drying methods for sustainable food production: impact on bioactive components, texture, color, and sensory properties of food. Journal of Texture Studies 53(6): 737–762. https://doi.org/10.1111/jtxs.12643

Parniakov, O., Bals, O., Lebovka, N. and Vorobiev, E. 2016. Effects of pulsed electric fields assisted osmotic dehydration on freezing-thawing and texture of apple tissue. Journal of Food Engineering 183: 32–38. https://doi.org/10.1016/J.JFOODENG.2016.03.013

Pravitha, M., Manikantan, M.R., Ajesh Kumar, V., Beegum, S. and Pandiselvam, R. 2021. Optimization of process parameters for the production of jaggery infused osmo-dehydrated coconut chips. Food Science and Technology (LWT) 146: 111441. https://doi.org/10.1016/J.LWT.2021.111441

Pravitha, M., Manikantan, M.R., Ajesh Kumar, V., Shameena Beegum, P.P. and Pandiselvam, R. 2022. Comparison of drying behavior and product quality of coconut chips treated with different osmotic agents. Food Science and Technology (LWT) 162: 113432. https://doi.org/10.1016/J.LWT.2022.113432

Priya, K., Thirunavookarasu, N. and Chidanand, D.V. 2023. Recent advances in edible coating of food products and its legislations: a review. Journal of Agriculture and Food Research 12: 100623. https://doi.org/10.1016/j.jafr.2023.100623

Rahaman, A., Zeng, X.A., Kumari, A., Rafiq, M., Siddeeg, A., Manzoor, M.F., Baloch, Z. and Ahmed, Z. 2019. Influence of ultrasound-assisted osmotic dehydration on texture, bioactive compounds and metabolites analysis of plum. Ultrasonics Sonochemistry 58: 104643. https://doi.org/10.1016/J.ULTSONCH.2019.104643

Rahman, S.M.A., Sharma, P. and Said, Z. 2022. Application of response surface methodology based D-optimal design for modeling and optimisation of osmotic dehydration of Zucchini. Digital Chemical Engineering 4: 100039. https://doi.org/10.1016/j.dche.2022.100039

Ramallo, L.A., Hubinger, M.D. and Mascheroni, R.H. 2013. Effect of pulsed vacuum treatment on mass transfer and mechanical properties during osmotic dehydration of pineapple slices. International Journal of Food Engineering 9(4): 403–412. https://doi.org/10.1515/ijfe-2012-0059

Ramya, V. and Jain, N.K. 2017. A review on osmotic dehydration of fruits and vegetables: an integrated approach. Journal of Food Process Engineering 40(3): e12440. https://doi.org/10.1111/jfpe.12440

Ranjani, M., Shivaswamy, G., Abarna, S. and Rudra, S.G. 2024. Osmotic dehydration with low-calorie sweeteners: fruit preservation for generation z. AgriTech Today 1: 45–49.

Ranjha, M.M.A.N., Kanwal, R., Shafique, B., Arshad, R.N., Irfan, S., Kieliszek, M., Kowalczewski, P.Ł., Irfan, M., Khalid, M.Z., Roobab, U. and Aadil, R.M. 2021. A critical review on pulsed electric field: a novel technology for the extraction of phytoconstituents. Molecules 26(16): 4893. https://doi.org/10.3390/molecules26164893

Rastogi, N.K. and Raghavarao, K.S.M.S. 2004. Increased mass transfer during osmotic dehydration of-irradiated potatoes. Journal of Food Science 69(6): E259-E263. https://doi.org/10.1111/j.1365-2621.2004.tb10995.x

Rastogi, N.K., Raghavarao, K.S.M.S. and Niranjan, K. 2014. Recent developments in osmotic dehydration. In Sun, D.W. (eds)

Emerging Technologies for Food Processing (Second Edition). Academic Press, Elsevier, pp 181–212. https://doi.org/10.1016/B978-0-12-411479-1.00011-5

Reyes-Alvarez, C.A. and Lanari, M.C. 2023. Effect of freezing, osmodehydro-freezing, freezedrying and osmodehydro-freeze-drying on the physicochemical and nutritional properties of Arazá (*Eugenia stipitata* McVaugh). Food Chemistry Advances 3: 100496. https://doi.org/10.1016/J.FOCHA.2023.100496

Rice, T., Emanuele, Z., Elke, K.A. and and Coffey, A. 2020. A review of polyols – biotechnological production, food applications, regulation, labeling and health effects. Critical Reviews in Food Science and Nutrition 60(12): 2034–2051. https://doi.org/10.1080/10408398.2019.1625859

Rubio-Arraez, S., Capella, J.V., Ortolá, M.D. and Castelló, M.L. 2015. Modelling osmotic dehydration of lemon slices using new sweeteners. International Journal of Food Science and Technology 50(9): 2046–2051. https://doi.org/10.1111/ijfs.12859

Şahin, U. and Öztürk, H.K. 2016. Effects of pulsed vacuum osmotic dehydration (PVOD) on drying kinetics of figs (*Ficus Carica* L). Innovative Food Science and Emerging Technologies 36: 104–11. https://doi.org/10.1016/j.ifset.2016.06.003

Said, L.B.H., Bellagha, S. and Allaf, K., 2015a. Measurements of texture, sorption isotherms and drying/rehydration kinetics of dehydrofrozen-textured apple. Journal of Food Engineering 165: 22–33. https://doi.org/10.1016/j.jfoodeng.2015.04.029

Said, L.B.H., Bellagha, S. and Allaf, K. 2015b. Optimization of instant controlled pressure drop (DIC)-assisted dehydrofreezing using mechanical texture measurements versus initial water content of apple. Food and Bioprocess Technology 8(5): 1102–1112. https://doi.org/10.1007/s11947-015-1475-2

Said L.B.H., Bellagha, S. and Allaf, K. 2016. Dehydrofreezing of apple fruits: freezing profiles, freezing characteristics, and texture variation. Food and Bioprocess Technology 9(2): 252–261. https://doi.org/10.1007/s11947-015-1619-4

Salehi, F., Cheraghi, R. and Rasouli, M. 2022. Mass transfer kinetics (soluble solids gain and water loss) of ultrasound-assisted osmotic dehydration of apple slices. Scientific Reports 12(1): 15392. https://doi.org/10.1038/s41598-022-19826-w

Salehi, F., Cheraghi, R. and Rasouli, M. 2023. Mass transfer analysis and kinetic modeling of ultrasound-assisted osmotic dehydration of kiwifruit slices. Scientific Reports 13(1): 11859. https://doi.org/10.1038/s41598-023-39146-x

Samborska, K., Eliasson, L., Marzec, A., Kowalska, J., Piotrowski, D., Lenart, A. and Kowalska, H. 2019. The effect of adding berry fruit juice concentrates and by-product extract to sugar solution on osmotic dehydration and sensory properties of apples. Journal of Food Science and Technology 56(4): 1927–1938. https://doi.org/10.1007/s13197-019-03658-0

Santos, M.D., Inácio, R.S., Fidalgo, L.G., Queirós, R.P., Moreira, S.A., Duarte, R.V., Gomes, A.M.P., Delgadillo, I. and Saraiva, J.A. 2019. Impact of high-pressure processing on food quality. In: Roohinejad, S., Koubaa, M., Greiner, R. and Mallikarjunan, K. (eds) Effect of Emerging Processing Methods on the Food Quality. Springer, New York, NY, pp. 95–131.

Semenoglou, I., Dimopoulos, G., Tsironi, T. and Taoukis, P. 2020. Mathematical modelling of the effect of solution concentration and the combined application of pulsed electric fields on mass transfer during osmotic dehydration of sea bass fillets. Food and Bioproducts Processing 121: 186–192. https://doi.org/10.1016/j.fbp.2020.02.007

Serment-Moreno, V., Barbosa-Cánovas, G., Torres, J.A., and Welti-Chanes, J. 2014. High-pressure processing: kinetic models for microbial and enzyme inactivation. Food Engineering Reviews 6: 56-88. https://doi.org/10.1007/s12393-014-9075-x

Sette, P., Salvatori, D. and Schebor, C. 2016. Physical and mechanical properties of raspberries subjected to osmotic dehydration and further dehydration by air- and freeze-drying. Food and Bioproducts Processing 100: 156–171. https://doi.org/10.1016/j.fbp.2016.06.018

Shete, Y.V, Chavan, S.M., Champawat, P.S. and Jain, S.K. 2018. Reviews on osmotic dehydration of fruits and vegetables. Journal of Pharmacognosy and Phytochemistry 7: 1964–1969.

Silva Barros de Oliveira, M.H. da, Ferreira Filho, A.J.M., Silva Júnior, E.V. da, Silva, E.S. da, Paim, A.P.S., Honorato, F.A. and Azoubel, P.M. 2021. Impregnation and drying to develop a melon snack enriched in calcium. Journal of Food Science and Technology 58(2): 672–679. https://doi.org/10.1007/s13197-020-04581-5

Silva, K.S., Fernandes, M.A. and Mauro, M.A. 2014. Effect of calcium on the osmotic dehydration kinetics and quality of pineapple. Journal of Food Engineering 134: 37–44. https://doi.org/10.1016/J.JFOODENG.2014.02.020

Sittiisuanjik, K., Chottanom, P., Moongngarm, A. and Deeseenthum, S. 2021. Pulsed vacuum osmotic dehydration on physiological compound enrichment of model food. Journal of Sustainability Science and Management 16(2): 39–53. https://doi.org/10.46754/jssm.2021.02.006

Siwach, S., Yadav, B.S., Yadav, R. and Dalal, N. 2025. Osmo-convective dehydration of pineapple cubes using jaggery and coconut sugar as non-conventional osmotic agents. Journal of Food Measurement and Characterization 19: 2532–2545. https://doi.org/10.1007/s11694-025-03129-5

Srijaya, M. and Shanthti, P.B. 2017. Impact of gamma irradiation and osmotic dehydration on quality characteristics of guava (*Psidium guajava*) slices. Asian Journal of Dairy and Food Research 36: 1–15. https://doi.org/10.18805/ajdfr.v36i03.8964

Srinivas, M., Madhu, B., Girijal, S. and Jain, S. 2018. High-pressure processing of foods: a review. The Andhra Agricultural Journal 65: 467–476.

Sriraaman, M., Meenakshi, M. and Kaliga Rani, J. 2021. A review on osmotic dehydration technique and its scope in startup industries. International Journal of Modern Agriculture 10(1): 176–179.

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. Food Science and Technology (LWT) 98: 179–186. https://doi.org/10.1016/j.lwt.2018.08.032

Šuput, D., Rakita, S., Spasevski, N., Tomičić, R., Dragojlović, D., Popović, S. and Hromiš, N. 2024. Dried beetroots: optimization of the osmotic dehydration process and storage stability. Foods 13(10): 1494. https://doi.org/10.3390/foods13101494

Surendhar, A., Sivasubramanian, V., Vidhyeswari, D. and Deepanraj, B. 2019. Energy and exergy analysis, drying kinetics, modeling and quality parameters of microwave-dried turmeric slices. Journal of Thermal Analysis and Calorimetry 136(1): 185–197. https://doi.org/10.1007/s10973-018-7791-9

Taiwo, K.A., Angersbach, A. and Knorr, D. 2003. Effects of pulsed electric field on quality factors and mass transfer during osmotic dehydration of apples. Journal of Food Process Engineering 26: 31–48. https://doi.org/10.1111/j.1745-4530.2003.tb00588.x

Taiwo, K.A., Angersbach, A. and Knorr, D. 2012. Influence of high intensity electric field pulses and osmotic dehydration on the rehydration characteristics of apple slices at different temperatures. Journal of Food Engineering 52: 185–192. https://doi.org/10.1016/S0260-8774(01)00102-9

Tylewicz, U., Tappi, S., Genovese, J., Mozzon, M. and Rocculi, P. 2019. Metabolic response of organic strawberries and kiwifruit subjected to PEF assisted-osmotic dehydration. Innovative Food Science & Emerging Technologies 56: 102190. https://doi.org/10.1016/j.ifset.2019.102190

Tylewicz, U., Tappi, S., Mannozzi, C., Romani, S., Dellarosa, N., Laghi, L., Ragni, L., Rocculi, P. and Dalla Rosa, M. 2017. Effect of pulsed electric field (PEF) pre-treatment coupled with osmotic dehydration on physico-chemical characteristics of organic strawberries. Journal of Food Engineering 213: 2–9. https://doi.org/10.1016/j.jfoodeng.2017.04.028

Viana, A.D., Corrêa, J.L.G. and Justus, A. 2014. Optimisation of the pulsed vacuum osmotic dehydration of cladodes of fodder palm. International Journal of Food Science & Technology 49(3): 726–732. https://doi.org/10.1111/ijfs.12357

Wang, J. and Chao, Y. 2003. Effect of gamma irradiation on quality of dried potato. Radiation Physics and Chemistry 66(4): 293–297. https://doi.org/10.1016/S0969-806X(02)00388-2

Wang, X. and Feng, H. 2023. Pea protein isolate and inulin as plant-based biomacromolecules for reduction of sugar uptake in osmotic dehydration. Journal of Food Process Engineering 46(9): e14417. https://doi.org/10.1111/jfpe.14417

Wiktor, A., Śledź, M., Nowacka, M., Chudoba, T. and Witrowa-Rajchert, D. 2014. Pulsed electric field pretreatment for osmotic dehydration of apple tissue: experimental and mathematical modeling studies. Drying Technology 32(4): 408–417. https://doi.org/10.1080/07373937.2013.834926

Wu, X.F., Zhang, M., Mujumdar, A.S. and Yang, C.H. 2020. Effect of ultrasound-assisted osmotic dehydration pretreatment on the infrared drying of pakchoi stems. Drying Technology 38(15): 2015–2026. https://doi.org/10.1080/07373937.2019.1608232

Yazidi, R., Yeddes, W., Rybak, K., Witrowa-Rajchert, D., Wannes, W.A., Hammami, M., Hessini, K., Tounsi, M.S. and Nowacka, M. 2024. Osmotic dehydration of orange fruits in sucrose and prickly pear molasses solutions: mass transfer and quality of dehydrated products. Polish Journal of Food and Nutrition Sciences 74(4): 340–349. https://doi.org/10.31883/pjfns/194785

Yu, Y., Jin, T.Z., Fan, X. and Wu, J. 2018. Biochemical degradation and physical migration of polyphenolic compounds in osmotic dehydrated blueberries with pulsed electric field and thermal pretreatments. Food Chemistry 239: 1219–1225. https://doi.org/10.1016/j.foodchem.2017.07.071

Zalpouri, R., Kaur, P. and Sain, M. 2020. Refractive window drying – a better approach to preserve the visual appearance of dried products. Pantnagar Journal of Research 18(1): 90–94.

Zalpouri, R., Singh, M., Kaur, P. and Singh, S. 2022. Refractance window drying – a revisit on energy consumption and quality of dried bio-origin products. Food Engineering Reviews 14: 257–270. https://doi.org/10.1007/s12393-022-09313-3

Zeeshan, M., Ayub, M. and Khan, A. 2016. Preservation through osmotic dehydration. Research & Reviews: Journal of Food and Dairy Technology 4(4): 1–3.

Zhao, J.H., Hu, R., Xiao, H.W., Yang, Y., Liu, F., Gan, Z.L. and Ni, Y.Y. 2014. Osmotic dehydration pretreatment for improving the quality attributes of frozen mango: effects of different osmotic solutes and concentrations on the samples. International Journal of Food Science and Technology 49(4): 960–68. https://doi.org/10.1111/ijfs.12388

Zhao, J.H., Xiao, H.W., Ding, Y., Nie, Y., Zhang, Y., Zhu, Z. and Tang, X.M. 2017. Effect of osmotic dehydration pretreatment and glassy state storage on the quality attributes of frozen mangoes under long-term storage. Journal of Food Science and Technology 54(6): 1527–1537. https://doi.org/10.1007/s13197-017-2584-x

Zielinska, M., Sadowski, P. and Błaszczak, W. 2015. Freezing/thawing and microwave-assisted drying of blueberries (*Vaccinium corymbosum* L.). Food Science and Technology (LWT) 62(1): 555–563. https://doi.org/10.1016/j.lwt.2014.08.002

Zielinska, M., Zielinska, D. and Markowski, M. 2018. The effect of microwave-vacuum pretreatment on the drying kinetics, color and the content of bioactive compounds in osmo-microwave-vacuum dried cranberries (*Vaccinium macrocarpon*). Food and Bioprocess Technology 11(3): 585–602. https://doi.org/10.1007/s11947-017-2034-9

Zongo, P.A., Khalloufi, S., Mikhaylin, S. and Ratti, C. 2022. Pulsed electric field and freeze-thawing pretreatments for sugar uptake modulation during osmotic dehydration of mango. Foods 11(17): 2551. https://doi.org/10.3390/foods11172551