Received: 8 September 2019 Revised: 19 January 2020 Accepted article published: 23 January 2020 Published online in Wiley Online Library: 17 February 2020

(wileyonlinelibrary.com) DOI 10.1002/jsfa.10284

Application of non-thermal pretreatment techniques on agricultural products prior to drying: a review

Richard Osae,[a,b] **Gloria Essilfie,**[c] **Raphael N Alolga,**[d] **Selorm Akaba,**[e] **Xiaoqian Song,**[a] **Patrick Owusu-Ansah**[a] **and Cunshan Zhou**[a,b*]

Abstract

BACKGROUND: Most agricultural crops contain high moisture content (80–95% wet basis (wb)) which makes them very susceptible to microbial damage leading to shorter shelf-life and high postharvest losses. The high perishability of these agricultural products requires preservation techniques to prolong their shelf-lives. Drying remains an important component of processing in this regard. Therefore, any pretreatment methods for drying agricultural product that decreases the moisture content and minimizes drying time by conserving the quality of the crop product is of prime significance. This article is a comprehensive review of recent developments of non-thermal pretreatment (NTP) methods. A summary of their significance, emerging and innovative methods of this technology together with its applications and limitations are discussed. This article further examines the environmental impact of NTP techniques.

RESULTS: NTP techniques, such as high pressure, ultrasound, pulsed electric field and osmotic dehydration methods are essential operations for pre-dehydration of agricultural products prior to drying. These techniques can avoid the deleterious effects of heat on nutritive value, colour and flavour of agricultural products compared to thermal pretreatments. They also enhance the inactivation of the enzymes, improve energy efficiency and mass transfer, reduce processing time, preserve bioactive compounds, improve drying kinetics and drying rate, minimize enzymatic browning, and enhance product quality.

CONCLUSION: These findings will provide a better understanding of different NTP methods and also make available more information for selecting pretreatment techniques for drying of agricultural products.

Keywords: non-thermal pretreatment (NTP) techniques; high pressure (HP); ultrasound (US); pulsed electric field (PEF); osmotic dehydration (OD)

INTRODUCTION

Agricultural crops such as fruits, spices, vegetables, herbs, root and tubers, etc. are thermo-sensitive products with high nutritional, pharmacological as well as phytochemical properties (antioxidant, bioactive compounds, etc.) and these properties account for their numerous health potentials.[1–3] These crops contain high moisture content (80–95% wb) which makes them very susceptible to microbial damage leading to shorter shelf-lives and high postharvest losses.[4] Drying remains an important processing method that could conserve and extend the shelf-lives of these crops. It reduces the moisture content, delays decay and prolongs storage duration thus leading to enhancement of product quality.[5,6] However, conventional drying has been established to have a negative influence on the quality of the finished products (i.e. dried products) as well as the functional and nutritional compounds.[7,8] Hence, effective alternative pretreatment methods that are capable of reducing drying time while maintaining the quality are imperative.

Non-thermal pretreatment (NTP) techniques have been considered to be one of the most significant pretreatment technologies available for the preservation of agricultural crops. NTP technology has received much consideration in recent years due to its various benefits over traditional thermal technology, including short processing time, increased process efficiency and better product

---

* *Correspondence to: C Zhou, School of Food and Biological Engineering, Jiangsu University, Zhenjiang, 212013, PR China. E-mail: cunshanzhou@163.com*

a *School of Food and Biological Engineering, Jiangsu University, Zhenjiang P. R., China*

b *Technology Integration Base for Vegetable Dehydration Processing Ministry of Agriculture, Jiangsu University, Zhenjiang P. R., China*

c *College of Basic and Applied Sciences, Department of Crop Science, University of Ghana, Accra, Ghana*

d *State Key Laboratory of Natural Medicines, Department of Pharmacognosy, China Pharmaceutical University, Nanjing P. R., China*

e *Department of Agricultural Economics and Extension, School of Agriculture, College of Agriculture and Natural Sciences, University of Cape Coast, Cape Coast, Ghana*

quality amongst others.[9] It has been established that the NTP process does not involve heat generation but it can cause a change in temperature inside a product during processing.[10] In other words, these processes do not depend on the temperature of the source. High pressure (HP), ultrasound (US), pulsed electric field (PEF) and osmotic dehydration (OD) are examples of NTP technologies. Compared to thermal pretreatment, the NTP can prevent the damaging impacts on colour, flavour, and nutritive value of agricultural products.

HP processing is one of the pretreatments that advance the quality of the dried product. This pretreatment has been reported to improve interactions of covalent and non-covalent bonds during dehydration leading to enzyme inactivation and destruction of microorganism.[11] Similarly, the application of HP treatment preserves the secondary, tertiary, and quaternary structure of proteins such as amino acids as well as retention of aroma, flavour, vitamins and other phytochemical compounds.[10]

US is a promising NTP technique used in the food processing industry. It is normally used prior to drying of various agricultural products to improve the drying rate, drying time, mass transfer, reduce the cost of processing and preserve the quality properties.[12] The application of US results in a sponge-like effect on the surface of the solid food sample which forms microspores within the food material. This enhances higher water removal as well as lessen the processing time.[13] Ren *et al.*,[14] showed that US pretreatment preserved the bioactive compounds and antioxidants activity in dried onions slices. Khandpur and Gogate,[15] reported that US pretreatment enhanced the nutritional quality of carrot, spinach, sweet lime, orange and juices.

OD pretreatment has shown enormous potential in enhancing the mass transfer and lessening the drying time as well as preserving the nutritional and textural characteristics of the dehydrated products.[16] It involves the immersion of food material into a hypertonic solution causing the exchange of water and solutes.[17] Oladejo *et al.*,[7] revealed that OD pretreatment preserved the texture and nutritional content of sweet potato. The process of OD has also been applied as a pretreatment preceding drying of mushroom,[17] garlic,[18] tomato and papaya.[19] This pretreatment method can be used to prevent or reduce browning.

PEF is also a NTP technique that uses short pulses of electricity. This causes electroporation in the cell wall of microorganisms thereby inactivating them. Food processed by PEF meets consumers' demand for fresh-like products with minimal loss of quality.[20]

Non-thermal technologies offer numerous merits for food pretreatment, for example, homogeneity of treatment; minimal thermal damage; shelf-life similar to those treated thermally while retaining the food quality parameters and low energy requirement. Several studies have shown that NTP resulted in pretreated products with better quality.[9,21] Therefore, application of NTP technologies is crucial in order to lessen loss of quality in agricultural product preceding drying. The objectives of this article were to review (i) significance of NTP techniques; (ii) the influence on agricultural product and limitations of the existing NTP technologies such as HP, US, PEF and OD; (iii) the environmental impact of NTP techniques and (iv) recent development in NTP techniques.

EMERGING AND INNOVATIVE NTP TECHNOLOGY

Ultrasound (US)

Influence and advantages of US pretreatment techniques on the quality of agricultural products

US is a type of sound energy transmitted by waves in the form of pressure at frequencies of 20 kHz and above.[22] The application of US range in food processing and analysis can be categorized into two subclasses; high and low intensity (low and high energy). Low-energy (low-power, low-intensity) US has frequencies higher than 100 kHz at intensities below 1 W cm^{-2}. High-energy (high power, high-intensity) US uses intensities higher than 1 W cm^{-2} at frequencies between 20 and 500 kHz (see Fig. 1).[23,24] It is extensively explored on various parameters including antioxidant activity, colour properties, pH, vitamin C, non-enzymatic browning, enzyme inactivation and polyphenols of various agricultural crops (spices, fruits, herbs, vegetables).

Several works have been done to assess the influence of US pretreatment preceding drying on the physicochemical properties and microstructural alterations of various products. One of the important physical parameters of dehydrated product that enhance consumer acceptance and ensure microbiological stability is the total colour change and water activity respectively.[25–27] Kroehnke *et al.*,[28] studied the influence of US pretreatment on convective drying of potato and reported that the total colour change of dried potato significantly decreased when US was applied. The US application during the convective drying process of potato reduced the total colour change by about 8% and 12% at 100 and 200 W, respectively, in comparison to the convective process. They further reported that US application did not influence the water activity (a_w) of the dried potato. However, a_w values of potato were similar (below 0.6) for the convection drying process and the US pretreatment prior to the drying process. The activity of microorganism is inhibited in a_w below 0.6. As reported by Mierzwa and Kowalski,[29] the parameters of a_w and colour change were measured in assessing apple quality after US pretreatment preceding the drying process. The study revealed a

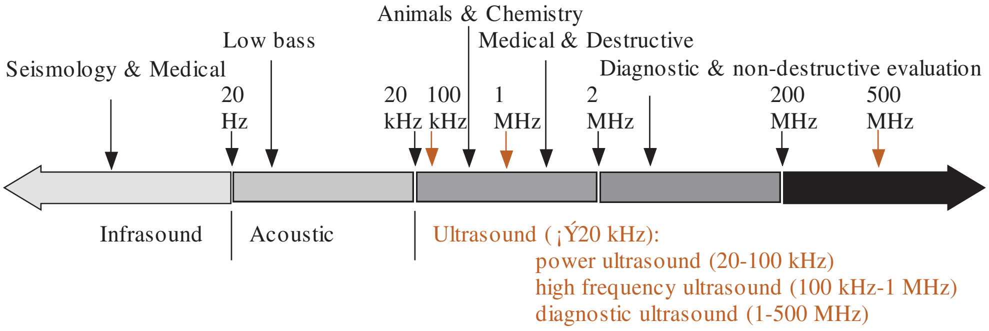

Figure 1. Frequency range of sound wave.

decrease in total colour change for convectively dried apple with US enhancement. The US application during convective drying of apple reduced the total colour change by about 32% at 200 W in comparison to the convective drying. US application did not influence the water activity of the dried apple. However, the water activity of the dried apple was lower than 0.4 for the convective drying process and the US-assisted convective drying process. The application of US greatly increases the drying kinetics, which resulted in a reduction of the overall drying time. Thus, the energy efficiency of the drying process represents an improvement leading to a reduction of energy consumption.[25] Meanwhile, US application may influence some physical properties of fruit, spices, herbs and vegetables such as colour change, water activity, porosity, and hardness, etc.

The advantages of using US in pretreatment of agricultural crops include:

- Effective against vegetative cells, spores, and enzymes
- Reduction of processing times
- Improvement in heat and mass transfer
- Possible alteration of texture and food structure
- Batch or continuous operation
- Influence on enzyme activity
- Better product quality and reduced energy savings
- Enhancement of drying rate.

Application of US

The application of US may minimize some of the challenges of conventional drying by enhancing the drying rate at reduced temperature. The use of US at a time duration of 15 to 30 min with a power range of 0 to 200 W has been reported to create micro channels within the cell structure which lead to the damage of the tissue components and an irreversible change to the cell structure.[30] According to Garcia-Perez *et al.*,[31] the application of US pretreatment on eggplant preceding convective drying resulted in a significant decrease of drying duration and conserved the microstructure. This outcome is in agreement with the findings of Rodríguez *et al.*,[32] who studied the influence of US (18.5 and 30.8 kW m^{-3}) pretreatment on the antioxidant properties, and bioactive compounds [total polyphenol content (TPC), and total flavonoid content (TFC)] of apple slices. They further reported that the US pretreatment retained a greater percentage of the antioxidant properties, TPC and TFC compared to apple slices dried without US pretreatment at the temperature range of 30 and 50 °C. Consequently, the authors proposed that this could be interesting for the preservation of phenolic compounds and the antioxidant activity when high-density US and lower drying temperature are applied. Wang *et al.*,[27] also showed that the application of US enhanced the convective drying process as shown in Table 1. Cruz *et al.*,[33] stated that the use of US pre-dehydration prior to drying of grapes and plums increases drying rate, and drying kinetics as well as improves the physical properties and the general quality aspects of the final products. Similarly, the application of US as a pretreatment has been established to reduce processing (drying) time as a result of an enhanced mass transfer. Its usage results in energy efficiency during drying by reducing the consumption of energy and enhancement of effective moisture diffusivity.[34] Kadam *et al.*,[35] stated that dried seaweed pretreated by US prior to drying improved the colour quality of the final product and reduced the drying time as well as energy cost. Moreover, the application of US can improve the quality parameters of products dried with US-assisted convective drying process.[30,32]

The use of US pretreatment has been found to inactivate enzymes such as peroxidase (POD) and polyphenol oxidase (PPO) and prevent possible deterioration reactions.[36] The underlying reactions of these enzymes can cause deterioration of agricultural crops particularly spices and herbs during storage, processing and transportation.[37] US pretreatment has been reported to be more effective at inactivating the PPO and POD enzymes. The mechanism involved in the inactivation of PPO and POD enzymes by US may be ascribed to the chemical and mechanical effects of cavitation.[9] The ultrasonic cavitation results in the creation and disintegration of micro bubbles which lead to high temperature and pressure during the sonication process. The fast bubble explosion caused by the US cavitation changes the environmental conditions (pressure, temperature, and shear forces) of the enzymes and damages the enzyme structure which results in the enzyme inactivation.[38–40] Sulaiman *et al.*,[38] further reported that application of US resulted in a decrease in PPO and POD activity during processing of apple, strawberry, and pear at a temperature of 32 °C. Cao *et al.*,[41] stated that the application of US pretreatment improves inactivation efficiency and lessens the inactivation time of POD and PPO enzymes during the processing of bayberry. US pretreatment whether with probe or in-bath led to a decrease in enzyme activities which is time- and temperature-dependent. However, US in bath treatment is less effective at shorter time and low temperature than the US-with probe (Figs 2 and 3). In other words, at lower temperature and shorter duration, the US-with probe is very effective.[42] Previous work of Sarpong *et al.*,[43] revealed that US pretreatment prior to drying reduces Non-enzymatic browning (NEB) on dried banana slices significantly compared to untreated samples. Low US pretreatment of daylilies prior to drying minimized NEB and improved the colour retention of the dried daylilies.[44] Ren *et al.*,[14] reported that US pretreatment of onion resulted in a higher preservation of TFC, TPC and antioxidant activity compared to the untreated samples. This result is consistent with what was reported by Santacatalina *et al.*[45] They stated that the application of US pretreatment preceding drying of apple preserved the antioxidant activity and other bioactive compounds. In agreement with these findings, Horuz *et al.*[46] who worked on US pretreatment for drying of tomato slices, reported that the US pretreatment retained some greater amount of TPC after hot air drying. The increase in the preservation of the bioactive compounds may be ascribed to an enhanced extraction efficiency as a result of US waves and cavitation as well as mechanical stress on the ginger sample which aided higher mass transfer.[47]

US pretreatment prior to drying has been established to enhance solid gain and water loss. The US pretreatment of carrot resulted in the lessening of the drying time and enhancement of mass transfer compared with the untreated samples.[27] Osae *et al.*,[48] reported that the use of US pretreatment technique facilitated the weight reduction, water loss, solid gain and shortened the drying time of ginger. According to Sarpong *et al.*,[49] the application of US treatment on banana slices prior to drying reduced the processing time and was more energy-efficient compared to the control (untreated).

Nowacka *et al.*,[12] established that lessening of processing time, effective mass transfer and moisture removal as well as improvement energy consumption are some of the merits of the US pretreatment technique. The enhancement of mass transfer is attributed to the liquid media in which the food sample is propagated as a result of the influence of cavitation which creates micro pores in the food samples (Fig. 4).The distorted disintegrations of bubbles formed close to the food sample can produce micro channels at the interface (surface of food sample) due to the

Table 1. Studies on ultrasound (US) treatment on agricultural crops

Material	Conditions	Main results	Reference
Carrot	20 kHz frequency with pulse durations of 5 s on and 5 s off, 1200 W LFU	LFU pretreatment caused the disruption of cell structures and formation of micro-channels, resulting in significant ($P < 0.05$) decrease in drying time required	56
Apple (Lobo)	Ultrasound frequency: 26 kHz; Ultrasound power: 100 W; Air velocity: 0.7 m s^{-1}; Air temperature: 45 °C	Ultrasound makes the drying processes more effective and enhances the drying efficiency of biological products without significantly raising their temperature	68
Carrot	Ultrasound frequency: 21.7 kHz; Ultrasound power: 75 W; Air velocity: 1 m s^{-1}; Air temperature: 40 °C	The power ultrasound application increased the mass transfer coefficient and the effective moisture diffusivity regardless of the mass load density used	126
Onion	20 kHz, for 1, 3 and 5 min or with blanching using hot water at 70 °C for 1, 3 and 5 min	The ultrasound treatment improved the retention of bioactive compounds and the antioxidant activity in onion slices dried either by freeze drying or hot-air drying	14
Grape skin (Bobal)	Ultrasound frequency: 21.7 kHz; Ultrasound power: 45 W; Air temperature: 40, 50, 60 and 70 °C	Both temperature and ultrasound application had a significant ($P < 0.05$) influence on the drying kinetics Ultrasound application reduced the antioxidant potential, probably due to oxidase activation and cell degradation	22
Green pepper	Ultrasound frequency: 26 kHz; Ultrasound power: 100 and 200 W; Air velocity: 2 m s^{-1}; Air temperature: 55 °C	Convective drying with the application of ultrasound and microwave shorten significantly the drying time, reduce the energy consumption and affect positively the quality factors	67
Passion fruit peel	Ultrasound frequency: 21.7 kHz; Ultrasound power: 30.8 kW m^{-3}; Air temperature: 40, 50, 60 and 70 °C	Ultrasound application reduced the loss of total phenolic content and maintained the antioxidant activity of dried passion fruit peel	127
Strawberry	Ultrasound frequency: 21.8 kHz; Ultrasound power: 30 and 60 W; Air velocity: 2 m s^{-1}; Air temperature: 40, 50, 60 and 70 °C	The applied acoustic power and temperature gave rise to a significant reduction of drying time (13–44%) and improvement in moisture diffusivity and the mass transfer coefficient	125,129
Tomato	25-kHz, 300 W output power at 0, 20, and 40 min	Ultrasound pretreatment significantly enhanced the quality of the final product	53
Ginger	33 kHz, 600 W, 30 min, 30 °C, and 10 s on and 5 s off (pulsating duration)	Enhanced the drying rate and retention of bioactive compounds	128
Sweet potato	28 kHz, 30 min and power of 300 W	Ultrasound pretreatment retained the colour quality of sweet potato	4
Bitter melon	Fixed ultrasound power of 1200 W for 15 min in a water bath (25 °C).	Ultrasound pretreatment accelerate water loss during drying processes, and contribute to a shorter drying time	130
Garlic	Ultrasonic bath at 30 °C for 30 min (35 kHz)	Increase the drying rate and preserved colour properties	131
Mulberry leaves	26 kHz for 30 min using a pulsating duration of 10 s (on) and 5 s (off) at constant power of 60 W.	Preservation of phenolic and antioxidant properties	120
Shiitake mushrooms	Ultrasonic wave at 28 kHz and 600 W for 15 min	Improvement in drying rate and overall quality	132
kiwifruit	35 kHz for 10, 20 and 30 min.	Advanced drying rate and shorter drying time due to micro channel creation	12
okra	20 kHz frequency at pre-treatment time of 10, 20 and 30 min	Enhancement of rehydration ratio and drying rate as well as quality properties	133

expansions and alternating compressions from the US sound waves resulting in a spongy-like effect. This reduces the total drying time and preserves energy.[50]

Limitation of US

The influence of US pretreatment on food depends largely on US parameters which include, power, pulsating ratio, frequencies and intensity, etc. During US treatment, the acoustic waves cause an induced expansion and compression on the cell structure of the food materials which results in protein denaturation as well as an increase of enzyme activity due to disintegration of higher molecular structures. This facilitates substrates to be more accessible by the enzymes. Conversely, the application of US has also been reported to reduce the amount of some nutrients particularly antioxidant properties, TPC and TFC during the pretreatment process as these leach into the processing water.[33]

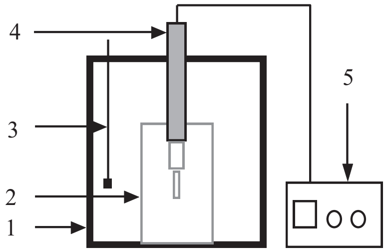

Figure 2. Schematic diagram of ultrasound with probe type treatment. 1, Thermostatic water bath; 2, sample pretreatment vessel; 3, thermometer; 4, probe-typed ultrasound; 5, ultrasonic generator.

High pressure (HP)

Influence and advantages of HP pretreatment techniques on the quality of agricultural products

Over the last 20 years, HP has been investigated on several commercial products, including carrots, apple, cabbage, grapefruits, orange and broccoli. The juices manufactured from these agricultural crops are processed by HP and are currently been sold on the market.[51,52] HP pretreatment technique have great and numerous importance in the food industry. Nutritionally, it enhances the availability of dietary nutrients by converting complex food into smaller ones.[53] HP has the ability to inactivate various food deteriorating enzymes without causing significant degradation to the nutritional and sensory qualities of the food products.[54] In general, the other merit of HP in pretreatment of food product include:

- Pressure is homogeneously applied throughout during food processing due to the consistency of the treatment
- There is less heat effect
- The storage life of the treated food product is extended comparable to food product that has been pasteurized thermally
- The application of HP pretreatment require less amount of energy.[55,56]

Application of HP pretreatments

Hite (1899) was the first scientist to apply HP in the processing of milk and other agricultural product. He stated that the use of HP pretreatment prolongs the storage and improves the quality of the food product. The industrial application of HP has been established to improve food safety, reduce food spoilage, maintain freshness of food products and preserve food products with less application of food preservatives.[57]

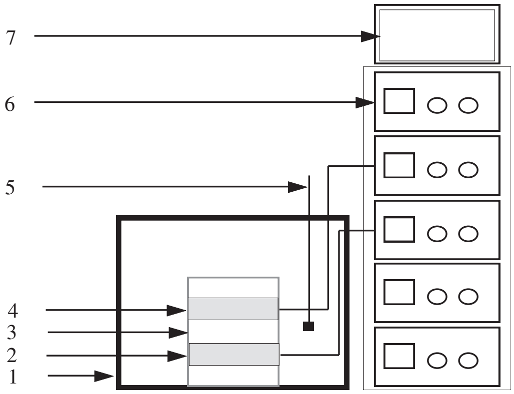

Figure 3. Schematic diagram of ultrasound with flat-typed treatment. 1, Thermostatic water bath; 2, flat-typed down ultrasound; 3, sample pretreatment vessel; 4, flat-typed up ultrasound; 5, thermometer; 6, ultrasonic generators; 7, computer control system.

The commercial use of HP includes subjecting food product (packaged and unpacked) to a pressure of 100 to 900 MPa in water for a time duration (1–20 min) at a temperature of 25 °C (room temperature). This process enhances the inactivation of enzymes and other deteriorating microorganism and retains the nutritive and physicochemical properties of the food sample.[51] Presently the use of HP in food processing (pretreatment) is an issue of major importance for food pretreatment prior to drying (food preparation) and preservation, since it uses pressure instead of heat in its operation. Food processing by HP has been studied by several researchers. These researchers have laid much emphasis on and paid specific attention to the biochemical, environmental, microbiological, technological and energy efficiency of the process.[51,52]

The HP application obeys the isostatic principle whereby a uniform pressure is instantaneously applied throughout the food sample (packed and unpacked) independent of the shape, composition and mass of the food sample (Fig. 5). The application of HP technology is gradually gaining prominence worldwide in the processing of a range of foods. It is used particularly in Japan where it was originated, in the Unites States and some parts of Europe. Its usage has been on the rise since 2000. In 2005, it was estimated that there were around 82 commercial-scale high-pressure food processing systems in use worldwide.[54] According to Danalache *et al*.,[58] the influence of HP and heat treatment on mango slices improved their storage life. The authors further established that HP prolonged the shelf life of treated mango compared to the untreated ones during 18 days of storage (see Table 2). Yucel *et al*.[59] studied the effect of HP pretreatment on the enhancement of the drying rate and product quality of carrot, apple, and green bean. The authors established that HP improved the drying process, reduced the drying time and yielded a product of higher quality. HP has been proven to be an effective technology for the improvement of the drying rate of many agricultural crops including *Aloe vera*,[53] strawberries,[60] cocoyam, sweet potato and carrot,[61] Dorantes-Alvarez *et al*.,[37] employed HP at low temperature with less treatment periods to preserve greater amount of bioactive compounds of dried pepper. They further suggested that the combined influence of HP and the treatment time resulted in the greater retention of the colour properties of the dried pepper samples.

Limitation of HP pretreatment

The HP systems comply with Le Chatelier–Braun principle – a principle that results in a reaction that causes reduction in the volume of the food samples. Such reactions affect the structure of large molecules (whose tertiary structure is vital for functionality), such as proteins. HP stimulates interactions of covalent and non-covalent bonds during food processing as a result of the pressure and causes protein denaturation.[56,62,63]

Osmotic dehydration (OD) pretreatment

Influence and advantages of OD pretreatment technique on the quality of agricultural products

OD is the exchange of water and solutes between the food material and the osmotic solution as a result of difference in osmotic pressure.[64,124] It is the removal of water from the fruit or vegetable to the osmotic solution and uptake of solute from the osmotic solution through the semi-permeable membrane of the fruit

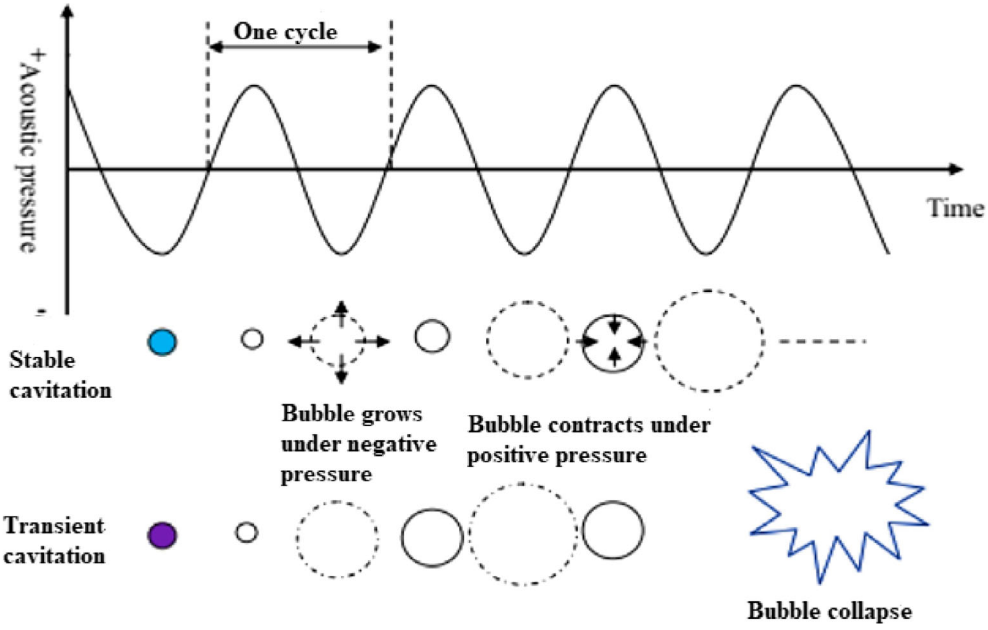

Figure 4. Ultrasonic waves and the cavitation phenomenon.

due to difference in osmotic concentration between the fruit and the solution.[65]

According to Chavan and Amarowicz,[66] the advantages of OD include:

- Minimization of the effects of temperature on the quality of foods and preservation of the freshness of foods, since no high temperature/phase change is involved
- Retention of colour and flavour leading to superior organoleptic properties, particularly when sucrose is the osmotic agent
- Increased resistance to heat treatment
- Simple and inexpensive process, and the energy use is two or three times less than that of the conventional drying
- Prevention of enzymatic browning and inhibition of activities of polyphenol oxidases
- Improvement of the texture and rehydration properties
- Elimination of the blanching process, thus reducing the cost of processing
- Modification of food composition and improvement on taste (candying effect) by the removal of acids and addition of sugar
- Decreasing the volume of the products, thereby reducing the cost of processing, storage and transportation
- Preservation of food structure even after further drying.

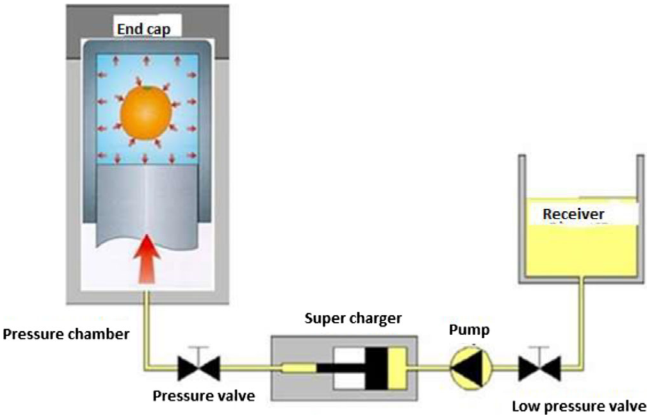

Figure 5. Principles of high pressure in food processing.

Application of OD pretreatment

The application of OD pretreatment is another strategy to improve the quality of agricultural products by inactivating enzymes and modifying the texture of their tissues preceding drying. Moreover, due to its chelating properties, some acids have the ability to retain product colour.[67] In general, OD is being used as a pretreatment technique preceding further drying in order to retain the functional, sensory and nutritional properties of food.[68] Osmotic agents commonly used in the OD of foods include salt, alcohol, sucrose, ethanol, calcium, corn syrup, fructose and their combinations.[69] The type of osmotic agents used sometimes depends on the food materials. In most cases, sucrose is appropriate for fruits while sodium chloride is suitable for vegetables and other crops (spices and herbs).[18,70] Recently Osae *et al.*,[48] used sucrose in OD pretreatment of ginger prior to drying and reported a higher retention of physicochemical properties.

Mamatha *et al.*,[71] assessed the influence of OD pretreatment of broccoli, capsicum bell pepper and onion by using 0.01% of sodium carbonate as osmotic agent for 5 min at a temperature of 70 °C and reported that the application of OD enhanced the level of β-carotene to 85%. This increase was ascribed to the inactivation of enzymes (PPO and POD) which are responsible for the destruction of carotenoid. Magdalena and Marek,[72] pretreated carrot slices with sodium triphosphate for 4 min at a temperature of 95 °C and revealed that the OD pretreatment significantly influenced the quality and retained the antioxidant properties. Several investigations have shown that OD pretreatment is the most effective treatment for reducing browning (see Table 3).

Numerous researchers have applied the OD technique to assess the quality properties of most dehydrated products and

Table 2. Studies on high pressure (HP) treatment used on agricultural crops

Product	Conditions	Results	Reference
Mango	500 MPa for 120 and 240 s	High pressure extended the shelf life of treated mango than the untreated mango bar during storage for 18 days	58
Spinach purée	200, 400 and 600 MPa for 5, 15 and 25 min at room temperature	Polyphenol oxidase (PPO) activity decreases when pressure increases. The time has no effect	134
Watermelon	10, 20, and 30 MPa at 50 °C, for 5, 15, 30, 45 and 60 min	Browning degree decreased pressure and treatment time	135
Apple	600 MPa for 1–5 min at 22 °C	The combined treatment significantly reduced residual PPO activity	61
Ginger	400 MPa for 5 min	HP allows reducing PPO activity by 37% whereas thermal treatment (100 °C, 10 min) reduces it by 10%	136
Lettuce	500 and 2500 lx	The intensity of 2500 lx protected from browning and quality decay by inhibiting browning-related enzyme activity	137
Green bean and Carrot	100–300 MPa for 5–45 min at 20 and 35 °C	Enhancement of the drying rate, reduced drying time and product quality	30
Aloe vera	350 MPa for 30 s	Improvement of drying kinetics and retention of antioxidant properties	31
Cocoyam and sweet potato	600 MPa for 5 and 30 min	Preserved the physical characteristics, and enhanced the drying rate	33
Cherry tomato	0.1–400 MPa and at 5 and 25 °C for 30 min	Useful choice for removing residual pesticides	138
Walnut	(300–600 MPa for 20 min)	HP treated walnut showed better foaming properties and *in vitro* digestibility	139
Rice	120, 240, 360, 480, and 600 MPa for 30 min	600 MPa for 30 min led to a complete gelatinization of rice starch granules	140
Banana	100–500 MPa, time (5–9 h) and temperature (30–70 °C)	Reduced dehydration time and energy consumption	141

established that OD pretreatment prior to drying enhanced the preservation of bioactive compounds and other physicochemical properties of the dried product. The application of OD has been reported to reduce oxidation browning particularly in fruits and vegetables.[73,74] The OD pretreatment of spinach, Mustard, and mint in potassium metabisulfite solution for a brief period (1 min) at a temperature of 95 °C resulted in preservation of the chlorophyll, *β*-carotene, reduced browning with minimum change in colour.[75] The main OD pretreatment and their application conditions are presented in Table 3. During OD pretreatment of agricultural crops prior to drying, solid gain (SG), weight reduction (WR) and water loss (WL) are some of the measured parameters. According to kaur et al.[75] solid gain usually occurs within 30 min while water loss happens 2 h after the OD process.

The measure of water that is removed from the food sample into the osmotic solution is defined as water loss. Sugar gain is the amount of solutes uptake by the food substance from the osmotic solution during OD. Weight reduction, however, is explained as the difference initial and final weight of the food sample before and after the OD process. The difference between the solid gain water loss can also be defined as WR.[76] Oladejo *et al.*[7] and Hamedi *et al.*[77] used the equations below to calculate, WR, SG and WL.

$$\mathrm{WL}\,(\%) = \frac{(w_0 - w_t) + (s_t - s_0)}{w_0} \times 100 \tag{1}$$

$$\mathrm{SG}\,(\%) = \frac{(s_t - s_0)}{w_0} \times 100 \tag{2}$$

where w_0 and w_t are the initial and final weights (in grams) of the sample, respectively; s_0 and s_t are the initial and final dry matter (in g kg^{-1}), respectively.

The WR was calculated according to Oladejo and Ma[65] as the difference between WL and SG:

$$\mathrm{WR}(\%) = \mathrm{WL} - \mathrm{SG} \tag{3}$$

Osae *et al.*,[78] reported that the application of OD preceding drying of ginger enhanced the drying rate and preserved the quality of the dried ginger. Osae *et al.*,[9] demonstrated that OD is an appropriate pretreatment method for deactivating a high percentage of the POD and PPO enzymes. They reported that the reduced POD and PPO activities in the ginger sample treated with OD may be ascribed to lower oxidative stress on the ginger surface due to the antioxidant ability of sucrose concentration.[74] This outcome was in agreement with Ma *et al.*,[79] who stated that the existence of sucrose and ascorbic acid effectively decreased the POD activity in dried-cut cantaloupe melon and other vegetables. Its application as a pretreatment, protects sensory properties and produces food product with minor quality losses.[80,81]

Xu *et al.*,[82] employed OD pretreatment in the dehydration of radish slices and reported that the application of OD enhanced mass transfer, conserved energy and reduced the processing time. Prosapio and Norton,[16] reported that the application of OD pretreatment prior to oven and freeze drying lessened the drying time and retained the bioactive compounds and the nutritional properties of strawberry. Osae *et al.*,[78] who worked on the OD pretreatment of ginger prior to drying reported the preservation of a greater percentage of the phenolic compounds in the dried ginger than the untreated samples. Similarly, García-Toledo *et al.*[83] also stated that OD pretreatment of Mexican ginger preceding hot air drying preserved the TFC and other chemical properties. Singla *et al.*[84] and Azeez *et al.*,[85] who worked on OD

Table 3. Studies on osmotic dehydration (OD) treatment used in agricultural crops

Products	Conditions	Results	References
Apple	Phytic acid (0.08%) at room temperature (RT)	Inhibition of the polyphenol oxidase (PPO) (99.2%)	142
	Ascorbic acid (0.3 mmol L^{-1}) for 10 min	Decrease in the browning	143
Kiwi	2% ascorbic acid +2% calcium chloride for RT/2 min	Treatment effective at delaying softening and browning	144
Watermelon	2% sodium chloride for RT	Preservation of the firmness of fresh-cut tissue throughout the storage	145
Pear	1-Methylcyclopropene (300 nL L^{-1}) then 2% ascorbic acid + 0.01% 4-hexylresorcinol + 1% calcium chloride for 0 °C/24 h 4 °C/15 min	Browning and softening are delayed	146
Eggplant	Calcium ascorbate or citrate (0.4%) For 60 °C/1 min	Calcium ascorbate was the best treatment to inactivate enzymes	147
Artichoke	Ascorbic acid, citric acid, cysteine and their combination, ethanol, sodium chloride, 4-hexylresorcinol for RT/1 min	Cysteine (0.5%) was the most effective treatment to prevent browning	148
Longan fruit	0.01% Sodium chlorite for RT/10 min	0.01% is the optimal concentration to reduce browning and PPO and peroxidase activities	149
Mushroom	DETANO (2,2′-(hydroxynitrosohydrazino)bisethnamine) at 0.5, 1 or 2 mmol L^{-1} for 20 °C/10 min	1 mmol L^{-1} of DETANO is sufficient to maintain a high level of firmness, to delay browning	150
Rose flower	Citric acid,; ascorbic acid, tartaric acid, and sucrose, Sucrose of different concentrations namely 0.1%, 1% and 2% *w/v*) for 12 h at RT	Resulted in the highest monomeric anthocyanins content and accelerate the drying process	151
Ginger	Sucrose 20% (*w/v*), at 30 °C and 30 min time	Enhanced drying kinetics and quality properties	57
Kiwifruit	61.5% sucrose solution equilibrated at 25 °C for a contact period of 0, 10, 20, 30, 60 and 120 min	Improved drying rate and reduced drying time	12
Sweet potato	Sucrose concentration of 35% *w/v* at 30 min	Enhancement the colour properties and of mass transfer	7
Goji berry	Glycerol (60% wt/wt), (20% wt/wt), ascorbic acid (2.0% wt/wt) and sodium chloride (1.0% wt/wt) at a time duration up to 180 min and 55 °C	Improved mass transfer, lessen drying time and quality	29
Yam	Sucrose (0.75 and 1.25 mol L^{-1}) at two durations (24 and 40 h)	Preservation of quality properties	152
Red bell pepper	Osmotic process duration (60–150 min), osmotic solution concentration 5% (*w/w*) to 20% (*w/w*), and osmotic solution temperature (30–60 °C),	Improvement in drying rate and quality properties	153

pretreatment of mushroom and tomato stated that the pretreated samples with strong browning showed very high antioxidant capacity than the untreated sample.

Limitation of OD pretreatment

Apart from the kind of osmotic agents, other factors that affect OD of agricultural products (fruit and vegetables) are concentration, temperature, time, the geometry of the food samples, agitation level of the solution, pretreatments type and so on.

Concentration. Increased osmotic solution concentration leads to an increase in water loss until equilibrium is reached, resulting in an increase in weight reductions.[78] Assis *et al.*,[69] explained that increase in mass transfer rate caused by the upsurge in osmotic solution concentration is as a result of an increase in the osmotic driving force between the surrounding solution and the sample. Increase in concentration of osmotic solution can also lead to deposit or uptake of the solute on the surface of the food material, which enhances the dewatering effect and reduces nutrients loss.[4] However, increased solute uptake on the surface of the food tissue can block the passage thereby making mass exchange difficult.[68]

Temperature. According to Bahmani *et al.*,[86] temperature is the most imperative factor affecting the rate of mass transfer during OD. Increase in temperature enhances the flow of water from the food material to the solution and the uptake of solutes from the solution to the food material because increase in temperature reduces the osmotic solution viscosity and also reduces the mass transfer between the surface and the solution.[87] Higher temperatures also cause plasticizing and swelling of cell membranes, which enhance faster water loss.[88]

Agitation of osmotic solution. Agitation enhances the mass transfer during OD due to reduced resistance by avoiding localization of the dilution process.[66] Increase in agitation leads to an increase in water loss, but low solid uptake. Agitation improves the contact between the osmotic solution concentration and the sample surface, thereby giving way for the difference in osmotic gradient.[89]

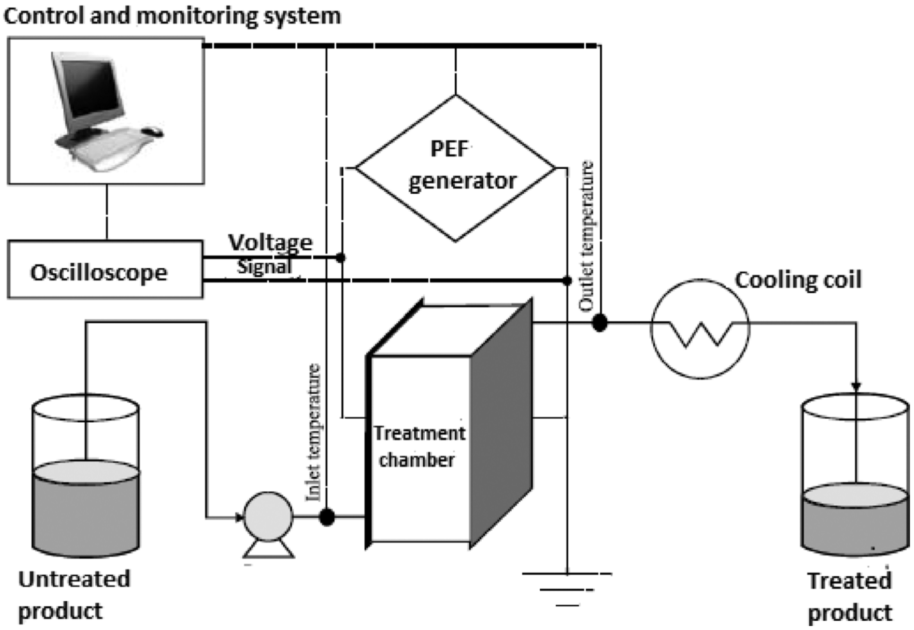

Figure 6. Principles of pulse electric field in the food processing.

Processing time. The processing time during OD influences the rate of mass transfer of water loss and solid gain.[90] It was suggested that one of the best ways to reduce solute uptake and to increase the ratio of water loss to solid gain is to interrupt the osmotic process at the early stage.[89] Processing time during OD helps to determine when the equilibrium water loss and equilibrium solid gain is reached. Studies have also shown that maximum mass exchange takes place at optimized time of the first 2 h.[66]

Pulsed electric field (PEF)

Influence of PEF techniques on the quality of agricultural products

Oms-Oliu,[91] extensively investigated the influence of PEF pretreatment (frequency 50–250 Hz, field strength 25–35 kV cm^{-1}, treatment time 50–2050 μs and pulse width 1–7 μs) on watermelon prior to dehydration. They established that the PEF treatment preserved the lycopene retention, vitamin C, bioactive compounds and other functional nutritional properties. They further attributed the improvement of the bioactive compounds and the functional properties of the watermelon to cell permeabilization and intracellular pigments release as a result of PEF-induction. The increase in the intensities of PEF may be ascribed to stress induction in the cells of the watermelon and successive production of lycopene as secondary metabolite stimulating metabolic activity.[20] Moussa-Ayoub *et al.*,[92] revealed that PEF pretreatment of twist spine prickly pear was observed to maintain the sensitive bioactive compounds such as antioxidant activity and phenolic content. Several authors revealed that PEF was able maintain the ascorbic acid, carotenoids and flavour compounds in longan juice, orange juice and also preserved the vitamins.[93,94]

These outcomes are consistent with the findings of Odriozola-Serrano *et al.*,[95] who revealed that PEF pretreatment at a constant field strength (35 kV cm^{-1}), treatment time (1000 μs), frequency of 232 Hz and a pulse width of 1 μs preserved greater percentages (87% and 102%) of health-related compounds (vitamin C, anthocyanins, and antioxidant capacity. Pertaining to earlier results, Morales-De La Peña *et al.*,[96] reported that, PEF treatment of pineapple, orange, and kiwi with the treatment time of 800 or 1400 μs was observed not to be different from the same product treated thermally at a temperature of 90 °C and a time of 60 s. Moreover, during storage (60 days) period the antioxidant properties of the PEF-treated products were much more preserved compared to the thermally-treated product.[97] Isomerization and oxidation that occurred during the thermal treatment resulted in the degradation of antioxidants. According to Soliva-Fortuny *et al.*,[98] PEF treatment (0.008 kJ kg^{-1}) of apple preceding drying enhanced the TPC and TFC compared to the untreated apple slices.

Application of PEF

PEF application is centred on pulses of high voltage (20–-80 kV cm^{-1}) which is usually positioned between a pair of electrodes that restrain the treatment gap of the PEF chamber (see Fig. 6).[99] The application of PEF helps in microorganism inactivation, retention of flavour, nutritional and functional properties of food product as a results of the limited heat intensities. The high field intensities of PEF are obtained through saving a greater amount of energy in a series of capacitors (capacitor bank) from direct power supply. This is then released in the form of high voltage pulses. This pulse from the electrical energy pass through the food material at a very reduced period of time and can be conducted at a reasonable temperature for a time interval (>1 s).[62]

For the preservation of agricultural product with PEF, the objectives of the electrical field strength is to enhance the extraction yield of plant food metabolites where the PEF generally works in a range 1–10 kV cm^{-1}.[100] PEF technology as a pretreatment improves the extraction yield of various plant food including carrot, sugar beet, grapes and apple (see Table 4).[47,101] According to Ortega-Rivas and Salmerón-Ochoa,[102] the application of PEF as a pretreatment step for coconut processing enhanced the retention of bioactive compounds compared to the untreated ones. They emphasized that further studies should be conducted on PEF

Table 4. Studies on pulsed electric field (PEF) treatment used in agricultural crops

Material	Conditions	Main results	Reference
Mushroom	4.8,12 and 28 J cm^{-2}	The use of high pulsed light (12 and 28 J cm^2) promoted enzymatic browning by an increase in polyphenol oxidase (PPO) activity	154
orange	3 and 10 $kVcm^{-1}$	The application of high electric field strength on orange peels enhanced the extraction of polyphenols up to 22 mg GAE g^{-1} dry matter	155
Apple	(PEF, 0.008–1.3 kJ kg^{-1}) at different temperatures (4 and 22 °C)	The mildest PEF treatment (0.008 kJ kg^{-1}) produced the maximum increases of total phenolics (13%) and flavan-3-ol (92%) contents in apples stored during 24 h at 22 °C, while it was observed at 4 °C for flavonoids (58%)	100
Tomato	(PEF) treatment was carried out using an NP110-60 system with an output voltage of 3.8 kV	Results showed that PEF and heating induced permeabilization of cell membranes in the tomato fractions	156
Goji berry	0.9–2.8 kV cm^{-1}, up to 7500 pulses)	Improved colour, retention of antioxidant activity and total phenolic content	29
Red Cabbage	PEF (2.5 kV cm^{-1} electric field strength; 15 μs pulse width and 50 pulses, specific energy 15.63 J g^{-1})	Enhanced total anthocyanin extraction	157
Carrot	PEF (0.1–1 kV cm^{-1}) and frequency (5–75 Hz) during PEF	Improved carotenoids extraction	158
Tomato waste	3–7 kV cm^{-1} and 0–300 μs	Improved carotenoid extraction from tomato peel	159
Waxy rice starch	(PEF) treatment at intensity of 30, 40 and 50 kV cm^{-1}	PEF treatment induced structural changes in waxy rice starch significantly affected its digestibility	160
Potato peels	0.75 kV cm^{-1} and 600 μs of treatment time	Enhanced the extraction of potato peel steroidal alkaloids.	161
Borage leaves	PEF (0–5 kV cm^{-1})	Improvement of the aqueous extraction of polyphenols and antioxidant compounds from borage leaves	162

pretreatment preceding drying of other crops to confirm its effect on the bioactive compounds of other agricultural crops.

Previous works of Donsì *et al.*[101] revealed that the application of PEF pretreatment preceding drying of potato and rell bell pepper shortened the dehydration time and enhanced the drying rate. Dermesonlouoglou *et al.*,[103] employed PEF pretreatment prior to drying of goji berries and reported of high drying rate and shorter drying duration. Donsì *et al.*[101] confirmed enhancement of mass transfer during PEF pretreatment of carrot, pepper and other vegetables. Wiktor *et al.*[104] and Janositz *et al.*[105] established that the use of PEF as a pretreatment prior to drying created pores in the tissues of apple and potato samples which resulted in an improved mass transfer and lessened the dehydration time.

PEF is another NTP method that has the capacity to inactivate enzymes during processing or pretreatments of agricultural products preceding drying. This pretreatment technique has been reported to have less destructive effects on the quality and nutritional properties of food products due to the non-existence of heat.[106] It has been reported to have the capacity to inactivate enzymes and avoid Maillard reactions during food processing.[41,107] According to Dermesonlouoglou *et al.*,[103] the application of PEF pretreatment prior to drying of goji berry enhanced the higher retention of phenolic compounds and antioxidant capacity of the dried samples compared to the untreated samples. Similarly, Ionică *et al.*,[108] stated that the use of PEF pretreatment led to higher preservation of TPC, TFC and antioxidant properties of dried goji berry fruits than the fresh ones.

Limitation of PEF

The various factors that affect the effectiveness of PEF technology include; cost, and design of equipment, suitability, characteristics of food products, and improper processing conditions.[109] Other limitations that affect the commercial application of PEF are:

- The capital intensiveness of PEF operations which limits its commercial application
- The persistence of spores and microorganism in food after processing resulting in rapid food spoilage
- The economic and technical limitations of purchasing the PEF equipment is limiting its usage in the food industries
- Only appropriate for liquids
- Scaling-up process may be difficult

ENVIRONMENTAL IMPACT OF NON-THERMAL TECHNOLOGIES

The energy consumption and energy savings of NTP techniques in the food industry have been one of the objective for the last 30 years. The NTP techniques (OD, HP, US and PEF) are continuously being evaluated as means of reducing energy consumption during processing, increasing reliability, improving productivity, and reducing emissions, resulting in products of higher quality.[110,111] Subsequently, these techniques have less effect on the environment. However, for many of the emerging technologies, that kind of information is still scarce or non-existent in published literature. Actual technology performance will depend on the facility, the application of the technology, and the existing production equipment with which the new technology is integrated.[47]

Many efforts have been dedicated to developing a sustainable industry. Reduction in the use of non-renewable energy resources lowers the emission of air pollutants such as carbon dioxide (CO_2), and an increase of the energy efficiency of devices is now a main worry for all processors. Moreover, if the electricity is generated by an environmentally clean, renewable energy source (e.g. hydroelectric power), then these processes will effectively contribute to reducing the pollution load, and help to preserve the environment. Furthermore, the NTP techniques such as HP for high pressure and PEF have been reported to reduce the utilization of cooling systems which often consume approximately 50% of the total electrical energy and are also responsible for pollutant emissions.[29,112]

RECENT DEVELOPMENT IN NTP METHODS

The combination of several NTP methods will enhance the protection of agricultural crops against deterioration by enzymes.[113] Osmosonication pretreatment is defined as the combined impact of US and OD.[78] This pretreatment technique has been established to retain phenolic compounds and inactivate quality-deteriorating enzymes. According to Osae *et al.*[48] the combined effect of US with OD significantly resulted in the high effectiveness of enzyme inactivation (PPO and POD) during ginger pretreatment (processing) preceding drying. Dehghannya *et al.*[114] and Amami *et al.*[115] showed that osmosonication pretreatment of strawberry and mirabelle plum prior to drying enhanced the mass transfer, improved the textural properties and preserved the antioxidants and bioactive compounds of the final product. Amami *et al.*,[115] reported that the application of osmosonication hastens the creation of free radical species and enhanced phenolic compounds polymerization. According to Hamedi *et al.*,[77] the highest preservation of TFC and TPC recorded during osmosonication pretreatment of pomegranate peel may be attributed to the combined influence of US and OD which caused rapid and high tissue softening and improved greater mass transfer leading to the decrease in the drying duration and retention of TFC.

Thermosonication is defined as the combined influence of ultrasound frequency and heat (temperature). Zhang *et al.*[44] also stated that the impact of US and temperature (thermosonication) enhanced PPO and POD enzymes during lettuce processing. Cheng *et al.*,[116] investigated the impact of thermosonication and thermal treatment on the inactivation kinetics of PPO in mushroom. They revealed that the synergistic effect of the US and temperature enhanced the inactivation kinetics of the PPO more rapidly than the thermal pretreatment. Xin *et al.*,[117] established that the best optimized and suitable procedure or conditions for inactivation of POD and retention of colour in argy wormwood leaves via thermosonication are the temperature of 85 °C, ultrasonic intensity of 11.94 W cm^{-2} and time of 60 s. Furthermore, Cao *et al.*,[41] reported that thermosonication treatment of bayberry enhanced the inactivation of enzymes (PPO and POD), TPC and colour properties.

Manosonication is the synergistic effect of US and high pressure.[118] Tchabo *et al.*,[119] explored the influence of manosonication treatment on the antioxidant properties and phenolic profile of Mulberry wine. Their results revealed that manosonication treatment retained greater amount of anthocyanin content, TFC, phenolic compounds and antioxidant properties. Previous works of Engmann *et al.*[120] confirmed that manosonication treatment reduces deterioration of pathogens in orange, apple and black mulberry juices as well as inactivation of PPO and POD enzymes. However, to accomplish the highest combined effect, it is significant and critical to assess the pressure level during processing.

Pulsed-high pressure (PEF + HP) is the combined influence of PEF and HP. Kaushik *et al.*,[121] studied the synergistic effect of PEF and HP on the inactivation enzymes in litchi juice and revealed that the pulsed-high pressure enhanced the inactivation of POD and PPO enzymes. Nuñez-Mancilla *et al.*[60] and Pérez-Won *et al.*[122] established that the application of high pressures combined with OD pretreatment of strawberry and red abalone preceding drying resulted in an improvement in mass transfer, higher drying rate, reduction of the drying period and energy consumption.

Zhang *et al.*,[123] studied the synergistic effects of ultrahigh pressure and US pretreatments on properties of strawberry chips prepared by vacuum-freeze drying and reported that the combined influence of ultrahigh pressure and US reduced the drying duration, energy consumption rate, improved the retention of antioxidation, and the overall quality of dried strawberry.

CONCLUSIONS AND FUTURE TRENDS

The use of NTP techniques in the food processing industry holds high prospects for producing and developing high-quality products. Present knowledge shows that treatment of agricultural products at high temperature usually affects and alters the levels of nutritional components and other bioactive compounds. The phenomenon by which bioactive compounds degrade or damage is complex, perplexing and numerous. Making sure food is safe and at the same time meeting the demand for quality and nutritious foods has led to higher interest in NTP techniques. These techniques demonstrate a fast, reliable and efficient alternative to enhancing the quality of agricultural product. It also has the prospective of developing new products with distinctive functionality. In general, these processing techniques can minimize the adverse effects of conventional processing on the levels of bioactive compounds, nutritional, pharmacological and phytochemical properties of agricultural products. There is an increased interest in application of these novel pretreatment techniques to improving the drying of various agricultural products and preserving their nutritional and physicochemical properties as well as the quality of the finished products.

However, the potential of these technologies have not been fully investigated for other agricultural products. Therefore, understanding the NTP processing mechanism in terms of the physical and chemical activities as well as functional properties on agricultural products would also contribute to and highlight the existence of their applications.

ACKNOWLEDGEMENTS

The authors wish to extend their profound appreciation for the assistance acquired from the National Key Research and Development Programme of China (2017YFD0400903-01, 2016YFD0400705-04, 2018YFD0700100-02), and the Policy Guidance Programme (Research Cooperation) of Jiangsu (BY2016072-03).

CONFLICT OF INTEREST

The authors declare no conflict of interest.

REFERENCES

1 Alolga RN, Chavez MA and Muyaba M, Untargeted UPLC-Q/TOF-MS-based metabolomics and inductively coupled plasma optical emission spectroscopic analysis reveal differences in the quality of ginger from two provinces in Zambia. *J Pharm Pharmacol* **70**:1262–1271 (2018).

2 Srinivasan K, Ginger rhizomes (*Zingiber officinale*): a spice with multiple health beneficial potentials. *PharmaNutrition* **5**:18–28 (2017).

3 Shukla A, Goud VV and Das C, Antioxidant potential and nutritional compositions of selected ginger varieties found in northeast India. *Ind Crops Prod* **128**:167–176 (2019).

4 Oladejo AO, Ma H, Qu W, Zhou C, Wu B and Yang X, Influence of ultrasound pretreatments on diffusion coefficients, texture and colour of osmodehydrated sweet potato (*Ipomea batatas*). *Int J Food Sci Technol* **52**:888–896 (2017).

5 An K, Zhao D, Wang Z, Wu J, Xu Y and Xiao G, Comparison of different drying methods on Chinese ginger (*Zingiber officinale* Roscoe): changes in volatiles, chemical profile, antioxidant properties, and microstructure. *Food Chem* **197**:1292–1300 (2016).

6 Wang J, Bai T-Y, Wang D, Fang X-M, Xue L-Y, Zheng Z-A *et al.*, Pulsed vacuum drying of Chinese ginger (*Zingiber officinale* Roscoe) slices: effects on drying characteristics, rehydration ratio, water holding capacity, and microstructure. *Drying Technol* **37**:301–311 (2018).

7 Oladejo AO, Ma H, Qu W, Zhou C and Wu B, Effects of ultrasound on mass transfer kinetics, structure, carotenoid and vitamin C content of osmodehydrated sweet potato (Ipomea batatas). *Food Bioprocess Technol* **10**:1162–1172 (2017).

8 Shamaei S, Emam-Djomeh Z and Moini S, Ultrasound-assisted osmotic dehydration of cranberries: effect of finish drying methods and ultrasonic frequency on textural properties. *J Texture Stud* **43**: 133–141 (2012).

9 Osae R, Zhou C, Xu B, Tchabo W, Tahir HE, Mustapha AT *et al.*, Effects of ultrasound, osmotic dehydration, and osmosonication pretreatments on bioactive compounds, chemical characterization, enzyme inactivation, color, and antioxidant activity of dried ginger slices. *J Food Biochem* **43**:e12832 (2019).

10 Bevilacqua A, Petruzzi L, Perricone M, Speranza B, Campaniello D, Sinigaglia M *et al.*, Nonthermal technologies for fruit and vegetable juices and beverages: overview and advances. *Compr Rev Food Sci Food Saf* **17**:2–62 (2018).

11 Silva JL, Oliveira AC, Vieira TC, de Oliveira GA, Suarez MC and Foguel D, High-pressure chemical biology and biotechnology. *Chem Rev* **114**:7239–7267 (2014).

12 Nowacka M, Tylewicz U, Laghi L, Dalla Rosa M and Witrowa-Rajchert D, Effect of ultrasound treatment on the water state in kiwifruit during osmotic dehydration. *Food Chem* **144**:18–25 (2014).

13 Mieszczakowska-Frąc M, Dyki B and Konopacka D, Effects of ultrasound on polyphenol retention in apples after the application of predrying treatments in liquid medium. *Food Bioprocess Technol* **9**: 543–552 (2016).

14 Ren F, Perussello C, Zhang Z, Kerry J and Tiwari B, Impact of ultrasound and blanching on functional properties of hot-air dried and freeze dried onions. *LWT Food Sci Technol* **87**:102–111 (2018).

15 Khandpur P and Gogate PR, Effect of novel ultrasound based processing on the nutrition quality of different fruit and vegetable juices. *Ultrason Sonochem* **27**:125–136 (2015).

16 Prosapio V and Norton I, Influence of osmotic dehydration pretreatment on oven drying and freeze drying performance. *LWT Food Sci Technol* **80**:401–408 (2017).

17 Tolera KD and Abera S, Nutritional quality of oyster mushroom (*Pleurotus ostreatus*) as affected by osmotic pretreatments and drying methods. *Food Sci Nutr* **5**:989–996 (2017).

18 Chenlo F, Pacios B, Mayor L, Vázquez M and Moreira R, Water desorption isotherms of raw and osmotically dehydrated garlic. *J Agr Sci Tech* **16**:1097–1107 (2018).

19 Siriamornpun S, Ratseewo J, Kaewseejan N and Meeso N, Effect of osmotic treatments and drying methods on bioactive compounds in papaya and tomato. *RSC Adv* **5**:18579–18587 (2015).

20 Haughton P, Lyng J, Cronin D, Morgan D, Fanning S and Whyte P, Efficacy of pulsed electric fields for the inactivation of indicator microorganisms and foodborne pathogens in liquids and raw chicken. *Food Control* **25**:131–135 (2012).

21 Wang J, Yang X-H, Mujumdar A, Wang D, Zhao J-H, Fang X-M *et al.*, Effects of various blanching methods on weight loss, enzymes inactivation, phytochemical contents, antioxidant capacity, ultrastructure and drying kinetics of red bell pepper (*Capsicum annuum* L.). *LWT Food Sci Technol* **77**:337–347 (2017).

22 Witrowa-Rajchert D, Wiktor A, Sledz M and Nowacka M, Selected emerging technologies to enhance the drying process: a review. *Drying Technol* **32**:1386–1396 (2014).

23 Shaheer C, Hafeeda P, Kumar R, Kathiravan T, Kumar D and Nadanasabapathi S, Effect of thermal and thermosonication on anthocyanin stability in jamun (*Eugenia jambolana*) fruit juice. *Int Food Res J* **21**:6–22 (2014).

24 Rastogi NK, Recent trends and developments in infrared heating in food processing. *Crit Rev Food Sci Nutr* **52**:737–760 (2012).

25 Szadzińska J, Łechtańska J, Kowalski SJ and Stasiak M, The effect of high power airborne ultrasound and microwaves on convective drying effectiveness and quality of green pepper. *Ultrason Sonochem* **34**:531–539 (2017).

26 Kowalski SJ and Pawłowski A, Intensification of apple drying due to ultrasound enhancement. *J Food Eng* **156**:1–9 (2015).

27 Wang L, Xu B, Wei B and Zeng R, Low frequency ultrasound pretreatment of carrot slices: effect on the moisture migration and quality attributes by intermediate-wave infrared radiation drying. *Ultrason Sonochem* **40**:619–628 (2018).

28 Kroehnke J, Musielak G and Boratynska A, Convective drying of potato assisted by ultrasound. *PhD Interdiscip J* **1**:57–65 (2014).

29 Mierzwa D and Kowalski SJ, Ultrasound-assisted osmotic dehydration and convective drying of apples: process kinetics and quality issues. *Chem Proc Eng* **37**:383–391 (2016).

30 Kowalski S, Mierzwa D and Stasiak M, Ultrasound-assisted convective drying of apples at different process conditions. *Drying Technol* **35**: 939–947 (2017).

31 Garcia-Perez VJ, Carmen O, Ana P, Juan C and Isabel P-M, Enhancement of water transport and microstructural changes induced by high-intensity ultrasound application on orange peel drying. *Food Bioprocess Technol* **5**:2256–2265 (2012).

32 Rodríguez Ó, Santacatalina JV, Simal S, Garcia-Perez JV, Femenia A and Rosselló C, Influence of power ultrasound application on drying kinetics of apple and its antioxidant and microstructural properties. *J Food Eng* **129**:21–29 (2014).

33 Cruz L, Clemente G, Mulet A, Ahmad-Qasem M, Barrajón-Catalán E and García-Pérez J, Air-borne ultrasonic application in the drying of grape skin: kinetic and quality considerations. *J Food Eng* **168**:251–258 (2016).

34 Elhussein EAA and Şahin S, Drying behaviour, effective diffusivity and energy of activation of olive leaves dried by microwave, vacuum and oven drying methods. *Heat Mass Transfer* **54**:1901–1911 (2018).

35 Kadam SU, Tiwari BK and O'Donnell CP, Effect of ultrasound pretreatment on the drying kinetics of brown seaweed *Ascophyllum nodosum*. *Ultrason Sonochem* **23**:302–307 (2015).

36 Carvalho LC and Zapata NCP, Kinetic and thermodynamic of thermal inactivation of the peroxidase, polyphenoloxidase and inulinase activities during blanching of yacon (*Smallanthus sonchifolius*) juice. *Food Bioproc Technol* **7**:3560–3568 (2014).

37 Dorantes-Alvarez L, Jaramillo-Flores E, González K, Martinez R and Parada L, Blanching peppers using microwaves. *Procedia Food Sci* **1**:178–183 (2011).

38 Sulaiman A, Soo MJ, Farid M and Silva FV, Thermosonication for polyphenoloxidase inactivation in fruits: modeling the ultrasound and thermal kinetics in pear, apple and strawberry purees at different temperatures. *J Food Eng* **165**:133–140 (2015).

39 Rodrigues S, Fernandes FA, García-Pérez JV and Cárcel JA, Influence of ultrasound-assisted air-drying and conventional air-drying on the activity of apple enzymes. *J Food Process Preserv* **41**:e12832 (2017).

40 Jabbar S, Abid M, Hu B, Wu T, Hashim MM, Lei S *et al.*, Quality of carrot juice as influenced by blanching and sonication treatments. *LWT Food Sci Technol* **55**:16–21 (2014).

41 Cao X, Cai C, Wang Y and Zheng X, The inactivation kinetics of polyphenol oxidase and peroxidase in bayberry juice during thermal and ultrasound treatments. *Innovative Food Sci Emerg Technol* **45**: 169–178 (2018).

42 Thanyanun R and Pilairuk I, Effects of high power ultrasonic pretreatment on physicochemical quality and enzymatic activities of dried longan. *J Agric Sci* **4**:299 (2012).

43 Sarpong F, Oteng-Darko P, Golly MK, Amenorfe LP, Rashid MT and Zhou C, Comparative study of enzymes inactivation and browning pigmentation of apple (*Malus domestica*) slices by selected gums during low temperature storage. *J Food Biochem* **42**:e12681 (2018).

44 Zhang Z, Niu L, Li D, Liu C, Ma R, Song J *et al.*, Low intensity ultrasound as a pretreatment to drying of daylilies: impact on enzyme inactivation, color changes and nutrition quality parameters. *Ultrason Sonochem* **36**:50–58 (2017).

45 Santacatalina J, Rodríguez O, Simal S, Cárcel J, Mulet A and García-Pérez J, Ultrasonically enhanced low-temperature drying of apple: influence on drying kinetics and antioxidant potential. *J Food Eng* **138**:35–44 (2014).

46 Horuz E, Jaafar HJ and Maskan M, Ultrasonication as pretreatment for drying of tomato slices in a hot air–microwave hybrid oven. *Drying Technol* **35**:849–859 (2017).

47 Rawson A, Patras A, Tiwari B, Noci F, Koutchma T and Brunton N, Effect of thermal and non thermal processing technologies on the bioactive content of exotic fruits and their products: review of recent advances. *Food Res Int* **44**:1875–1887 (2011).

48 Osae R, Zhou C, Xu B, Tchabo W, Bonah E, Alenyorege EA *et al.*, Non-thermal pretreatments enhances drying kinetics and quality properties of dried ginger (*Zingiber officinale* Roscoe) slices. *J Food Process Eng* **42**:e13117 (2019).

49 Sarpong F, Yu X, Zhou C, Amenorfe LP, Bai J, Wu B *et al.*, The kinetics and thermodynamics study of bioactive compounds and antioxidant degradation of dried banana (*Musa* ssp.) slices using controlled humidity convective air drying. *J Food Meas Char* **12**:1935–1946 (2018).

50 Ozuna C, Álvarez-Arenas TG, Riera E, Cárcel JA and Garcia-Perez JV, Influence of material structure on air-borne ultrasonic application in drying. *Ultrason Sonochem* **21**:1235–1243 (2014).

51 Kadam P, Jadhav B, Salve R and Machewad G, Review on the high pressure technology (HPT) for food preservation. *J Food Process Technol* **3**:135 (2012).

52 Rux G, Schlüter O, Geyer M and Herppich WB, Characterization of high hydrostatic pressure effects on fresh produce cell turgor using pressure probe analyses. *Postharvest Biol Technol* **132**:188–194 (2017).

53 Vega-Gálvez A, Uribe E, Perez M, Tabilo-Munizaga G, Vergara J, Garcia-Segovia P *et al.*, Effect of high hydrostatic pressure pretreatment on drying kinetics, antioxidant activity, firmness and microstructure of *Aloe vera* (*Aloe barbadensis* Miller) gel. *LWT Food Sci Technol* **44**: 384–391 (2011).

54 Tao Y, Sun D-W, Hogan E and Kelly AL, High-pressure processing of foods: an overview, in *Emerging Technologies for Food Processing*, 2nd edn. Sun D-W. Elsevier, Amsterdam, The Netherlands, pp. 3–24 (2015).

55 Chen D, Pang X, Zhao J, Gao L, Liao X, Wu J *et al.*, Comparing the effects of high hydrostatic pressure and high temperature short time on papaya beverage. *Innovative Food Sci Emerg Technol* **32**: 16–28 (2015).

56 Juarez-Enriquez E, Salmeron-Ochoa I, Gutierrez-Mendez N, Ramaswamy H and Ortega-Rivas E, Shelf life studies on apple juice pasteurised by ultrahigh hydrostatic pressure. *LWT Food Sci Technol* **62**:915–919 (2015).

57 Rivalain N, Roquain J and Demazeau G, Development of high hydrostatic pressure in biosciences: pressure effect on biological structures and potential applications in biotechnologies. *Biotechnol Adv* **28**:659–672 (2010).

58 Danalache F, Carvalho CY, Brito L, Mata P, Moldão-Martins M and Alves VD, Effect of thermal and high hydrostatic pressure treatments on mango bars shelf-life under refrigeration. *J Food Eng* **212**: 113–120 (2017).

59 Yucel U, Alpas H and Bayindirli A, Evaluation of high pressure pretreatment for enhancing the drying rates of carrot, apple, and green bean. *J Food Eng* **98**:266–272 (2010).

60 Nuñez-Mancilla Y, Perez-Won M, Vega-Gálvez A, Arias V, Tabilo-Munizaga G, Briones-Labarca V *et al.*, Modeling mass transfer during osmotic dehydration of strawberries under high hydrostatic pressure conditions. *Innovative Food Sci Emerg Technol* **12**:338–343 (2011).

61 de Oliveira MM, Tribst AAL, BRdCL J, de Oliveira RA and Cristianini M, Effects of high pressure processing on cocoyam, Peruvian carrot, and sweet potato: changes in microstructure, physical characteristics, starch, and drying rate. *Innovative Food Sci Emerg Technol* **31**: 45–53 (2015).

62 Pereira R and Vicente A, Environmental impact of novel thermal and non-thermal technologies in food processing. *Food Res Int* **43**: 1936–1943 (2010).

63 Escobedo-Avellaneda Z, Moure MP, Chotyakul N, Torres JA, Welti-Chanes J and Lamela CP, Benefits and limitations of food processing by high-pressure technologies: effects on functional compounds and abiotic contaminants (Beneficios y limitaciones del procesamiento de alimentos por tecnologías de alta presión: efectos en componentes funcionales y contaminantes abióticos). *CyTA J Food* **9**:351–364 (2011).

64 Yadav AK and Singh SV, Osmotic dehydration of fruits and vegetables: a review. *J Food Sci Technol* **51**:1654–1673 (2014).

65 Oladejo AO and Ma H, Optimisation of ultrasound-assisted osmotic dehydration of sweet potato (*Ipomea batatas*) using response surface methodology. *J Sci Food Agric* **96**:3688–3693 (2016).

66 Chavan U and Amarowicz R, Osmotic dehydration process for preservation of fruits and vegetables. *J Food Res* **1**:202 (2012).

67 Oliveira SM, Brandão TR and Silva CL, Influence of drying processes and pretreatments on nutritional and bioactive characteristics of dried vegetables: a review. *Food Eng Rev* **8**:134–163 (2016).

68 Azoubel PM, da Rocha AM, Oliveira SSB, Maciel MIS and Rodrigues JD, Improvement of water transport and carotenoid retention during drying of papaya by applying ultrasonic osmotic pretreatment. *Food Eng Rev* **7**:185–192 (2015).

69 Assis FR, Morais RM and Morais AM, Mass transfer in osmotic dehydration of food products: comparison between mathematical models. *Food Eng Rev* **8**:116–133 (2016).

70 Abdulmumeen HA, Risikat AN and Sururah AR, Food: its preservatives, additives and applications. *Int J Chem Biochem Sci* **1**:36–47 (2012).

71 Mamatha BS, Arunkumar R and Baskaran V, Effect of processing on major carotenoid levels in corn (*Zea mays*) and selected vegetables: bioavailability of lutein and zeaxanthin from processed corn in mice. *Food Bioprocess Technol* **5**:1355–1363 (2012).

72 Magdalena Z and Marek M, Color characteristics of carrots: effect of drying and rehydration. *Int J Food Prop* **15**:450–466 (2012).

73 Korus A and Lisiewska Z, Effect of preliminary processing and method of preservation on the content of selected antioxidative compounds in kale (*Brassica oleracea* L. var. *acephala*) leaves. *Food Chem* **129**: 149–154 (2011).

74 Jang J-H and Moon K-D, Inhibition of polyphenol oxidase and peroxidase activities on fresh-cut apple by simultaneous treatment of ultrasound and ascorbic acid. *Food Chem* **124**:444–449 (2011).

75 Kaur A, Kaur D, Oberoi D, Gill B and Sogi D, Effect of dehydration on physicochemical properties of mustard, mint and spinach. *J Food Process Preserv* **32**:103–116 (2008).

76 Pérez-Santaescolástica C, Carballo J, Fulladosa E, José VG-P, Benedito J and Lorenzo J, Application of temperature and ultrasound as corrective measures to decrease the adhesiveness in dry-cured ham. Influence on free amino acid and volatile compound profile. *Food Res Int* **114**:140–150 (2018).

77 Hamedi F, Mohebbi M, Shahidi F and Azarpazhooh E, Ultrasound-assisted osmotic treatment of model food impregnated with pomegranate peel phenolic compounds: mass transfer, texture, and phenolic evaluations. *Food Bioprocess Technol* **11**:1061–1074 (2018).

78 Osae R, Zhou C, Tchabo W, Xu B, Bonah E, Alenyorege EA *et al.*, Optimization of osmosonication pretreatment of ginger (*Zingiber officinale* Roscoe) using response surface methodology: effect on antioxidant activity, enzyme inactivation, phenolic compounds, and physical properties. *J Food Process Eng* **42**:e13218 (2019).

79 Ma L, Zhang M, Bhandari B and Gao Z, Recent developments in novel shelf life extension technologies of fresh-cut fruits and vegetables. *Trends Food Sci Technol* **64**:23–38 (2017).

80 Vervoort L, Van der Plancken I, Grauwet T, Timmermans RA, Mastwijk HC, Matser AM *et al.*, Comparing equivalent thermal, high pressure and pulsed electric field processes for mild pasteurization of orange juice: part II: impact on specific chemical and biochemical quality parameters. *Innovative Food Sci Emerg Technol* **12**:466–477 (2011).

81 Perera N, Gamage T, Wakeling L, Gamlath G and Versteeg C, Colour and texture of apples high pressure processed in pineapple juice. *Innovative Food Sci Emerg Technol* **11**:39–46 (2010).

82 Xu B, Zhang M, Bhandari B and Cheng X, Influence of ultrasound-assisted osmotic dehydration and freezing on the water state, cell structure, and quality of radish (*Raphanus sativus* L.) cylinders. *Drying Technol* **32**:1803–1811 (2014).

83 García-Toledo JA, Ruiz-López II, Martínez-Sánchez CE, Rodríguez-Miranda J, Carmona-García R, Torruco-Uco JG *et al.*, Effect of osmotic dehydration on the physical and chemical properties of Mexican

ginger (*Zingiber officinale* var. Grand Cayman). *CyTA J Food* **14**:27–34 (2016).

84 Singla R, Ganguli A and Ghosh M, Antioxidant activities and polyphenolic properties of raw and osmotically dehydrated dried mushroom (*Agaricus bisporous*) snack food. *Int J Food Prop* **13**:1290–1299 (2010).

85 Azeez L, Oyedeji AO, Adebisi SA, Adejumo AL and Tijani KO, Chemical components retention and modelling of antioxidant activity using neural networks in oven dried tomato slices with and without osmotic dehydration pre-treatment. *J Food Meas Char* **11**: 2247–2258 (2017).

86 Bahmani A, Jafari SM, Shahidi SA and Dehnad D, Mass transfer kinetics of eggplant during osmotic dehydration by neural networks. *J Food Process Preserv* **40**:815–827 (2016).

87 Phisut N, Factors affecting mass transfer during osmotic dehydrationof fruits. *Int Food Res J* **19**:7–18 (2012).

88 Bose S, Kuila T, Nguyen TXH, Kim NH, Lau K-T and Lee JH, Polymer membranes for high temperature proton exchange membrane fuel cell: recent advances and challenges. *Prog Polym Sci* **36**:813–843 (2011).

89 Tortoe C, A review of osmodehydration for the food industry. *Afr J Food Sci* **4**:303–324 (2010).

90 Nahimana H, Zhang M, Mujumdar AS and Ding Z, Mass transfer modeling and shrinkage consideration during osmotic dehydration of fruits and vegetables. *Food Rev Intl* **27**:331–356 (2011).

91 Oms-Oliu G, Aguilo-Aguayo I, Martin-Belloso O and Soliva-Fortuny R, Effects of pulsed light treatments on quality and antioxidant properties of fresh-cut mushrooms (Agaricus bisporus). *Postharvest Biol Technol* **56**:216–222 (2010).

92 Moussa-Ayoub TE, Jaeger H, Knorr D, El-Samahy S, Rohn S and Kroh LW, Impact of traditional and innovative technologies on some characteristics and bioactive compounds of *Opuntia macrorhiza* juice. *Procedia Food Sci* **1**:1410–1416 (2011).

93 Plaza L, Sánchez-Moreno C, De Ancos B, Elez-Martínez P, Martín-Belloso O and Cano MP, Carotenoid and flavanone content during refrigerated storage of orange juice processed by high-pressure, pulsed electric fields and low pasteurization. *LWT Food Sci Technol* **44**:834–839 (2011).

94 Rodríguez-Roque MJ, de Ancos B, Sánchez-Moreno C, Cano MP, Elez-Martínez P and Martín-Belloso O, Impact of food matrix and processing on the in vitro bioaccessibility of vitamin C, phenolic compounds, and hydrophilic antioxidant activity from fruit juice-based beverages. *J Funct Foods* **14**:33–43 (2015).

95 Odriozola-Serrano I, Soliva-Fortuny R and Martín-Belloso O, Impact of highintensity pulsed electric fields variables on vitamin C, anthocyanins and antioxidant capacity of strawberry juice. *LWT Food Sci Technol* **42**:93–100 (2009).

96 Morales-De La Peña M, Salvia-Trujillo L, Rojas-Graü M and Martín-Belloso O, Isoflavone profile of a high intensity pulsed electric field or thermally treated fruit juice-soymilk beverage stored under refrigeration. *Innovative Food Sci Emerg Technol* **11**:604–610 (2010).

97 Morales-de La Peña M, Elez-Martínez P and Martín-Belloso O, Food preservation by pulsed electric fields: an engineering perspective. *Food Eng Rev* **3**:94–107 (2011).

98 Soliva-Fortuny R, Vendrell-Pacheco M, Martín-Belloso O and Elez-Martínez P, Effect of pulsed electric fields on the antioxidant potential of apples stored at different temperatures. *Postharvest Biol Technol* **132**:195–201 (2017).

99 Mohamed ME and Eissa AHA, Pulsed electric fields for food processing technology, in *Structure and Function of Food Engineering*, ed. by AHA E. InTech, London, 206–226 (2012).

100 Gonzalez ME and Barrett DM, Thermal, high pressure, and electric field processing effects on plant cell membrane integrity and relevance to fruit and vegetable quality. *J Food Sci* **75**:2010 (2010)

101 Donsì F, Ferrari G and Pataro G, Applications of pulsed electric field treatments for the enhancement of mass transfer from vegetable tissue. *Food Eng Rev* **2**:109–130 (2010).

102 Ortega-Rivas E and Salmerón-Ochoa I, Nonthermal food processing alternatives and their effects on taste and flavor compounds of beverages. *Crit Rev Food Sci Nutr* **54**:190–207 (2014).

103 Dermesonlouoglou E, Chalkia A, Dimopoulos G and Taoukis P, Combined effect of pulsed electric field and osmotic dehydration pretreatments on mass transfer and quality of air dried goji berry. *Innovative Food Sci Emerg Technol* **49**:106–115 (2018).

104 Wiktor A, Śledź M, Nowacka M, Chudoba T and Witrowa-Rajchert D, Pulsed electric field pretreatment for osmotic dehydration of apple tissue: experimental and mathematical modeling studies. *Drying Technol* **32**:408–417 (2014).

105 Janositz A, Noack A-K and Knorr D, Pulsed electric fields and their impact on the diffusion characteristics of potato slices. *LWT Food Sci Technol* **44**:1939–1945 (2011).

106 Ranganathan K, Subramanian V and Shanmugam N, Effect of thermal and nonthermal processing on textural quality of plant tissues. *Crit Rev Food Sci Nutr* **56**:2665–2694 (2016).

107 Terefe NS, Yang YH, Knoerzer K, Buckow R and Versteeg C, High pressure and thermal inactivation kinetics of polyphenol oxidase and peroxidase in strawberry puree. *Innovative Food Sci Emerg Technol* **11**:52–60 (2010).

108 Ionică M, Nour V and Trandafir I, Polyphenols content and antioxidant capacity of goji fruits (*Lycium chinense*) as affected by the extraction solvents. *South Western J Hortic Biol Environ* **3**:121–129 (2012).

109 Da Cruz AG, Faria JAF, Saad SMI, Bolini HMA, Sant AS and Cristianini M, High pressure processing and pulsed electric fields: potential use in probiotic dairy foods processing. *Trends Food Sci Technol* **21**: 483–493 (2010).

110 Masanet E, *Energy Efficiency Improvement and Cost Saving Opportunities for the Fruit and Vegetable Processing Industry. An Energy Star Guide for Energy and Plant Managers*. Lawrence Berkeley National Laboratory, Berkeley, CA (2008).

111 Brush A, Masanet E and Worrell E, *Energy Efficiency Improvement and Cost Saving Opportunities for the Dairy Processing Industry: An ENERGY STAR? Guide for Energy and Plant Managers*. Lawrence Berkeley National Laboratory, Berkeley, CA (2011).

112 Delmas H and Barthe L, Ultrasonic mixing, homogenization, and emulsification in food processing and other applications, in *Power Ultrasonics*, ed. by Gallego-Juárez JA and Graff KF. Elsevier, Amsterdam, The Netherlands, pp. 757–791 (2015).

113 Ioannou I, Prevention of enzymatic browning in fruit and vegetables. *Eur Sci J* **9**:20–36 (2013).

114 Dehghannya J, Gorbani R and Ghanbarzadeh B, Effect of ultrasound-assisted osmotic dehydration pretreatment on drying kinetics and effective moisture diffusivity of mirabelle plum. *J Food Process Preserv* **39**:2710–2717 (2015).

115 Amami E, Khezami W, Mezrigui S, Badwaik LS, Bejar AK, Perez CT *et al.*, Effect of ultrasound-assisted osmotic dehydration pretreatment on the convective drying of strawberry. *Ultrason Sonochem* **36**: 286–300 (2017).

116 Cheng X-F, Zhang M and Adhikari B, The inactivation kinetics of polyphenol oxidase in mushroom (*Agaricus bisporus*) during thermal and thermosonic treatments. *Ultrason Sonochem* **20**:674–679 (2013).

117 Xin Y, Zhang M, Yang H and Adhikari B, Kinetics of argy wormwood (*Artemisia argyi*) leaf peroxidase and chlorophyll content changes due to thermal and thermosonication treatment. *J Food Sci Technol* **52**:249–257 (2015).

118 Sango DM, Abela D, McElhatton A and Valdramidis V, Assisted ultrasound applications for the production of safe foods. *J Appl Microbiol* **116**:1067–1083 (2014).

119 Tchabo W, Ma Y, Kwaw E, Zhang H, Li X and Afoakwah NA, Effects of ultrasound, high pressure, and manosonication processes on phenolic profile and antioxidant properties of a sulfur dioxide-free mulberry (*Morus nigra*) wine. *Food Bioprocess Technol* **10**:1210–1223 (2017).

120 Engmann FN, Ma Y, Tchabo W, Ma H and Zhang H, Optimization of ultrasonic and high hydrostatic pressure conditions on quality parameters of mulberry (*Morus* Moraceae) juice using response surface methodology. *J Food Qual* **37**:297–308 (2014).

121 Kaushik N, Kaur BP and Rao PS, Inactivation of polyphenol oxidase and peroxidase enzymes during pulsed, static and cyclic pressurization of litchi (*Litchi chinensis*) juice. *Food Bioprod Process* **100**: 412–423 (2016).

122 Pérez-Won M, Lemus-Mondaca R, Tabilo-Munizaga G, Pizarro S, Noma S, Igura N *et al.*, Modelling of red abalone (*Haliotis rufescens*) slices drying process: effect of osmotic dehydration under high pressure as a pretreatment. *Innovative Food Sci Emerg Technol* **34**: 127–134 (2016).

123 Zhang L, Liao L, Qiao Y, Wang C, Shi D, An K *et al.*, Effects of ultrahigh pressure and ultrasound pretreatments on properties of strawberry chips prepared by vacuum-freeze drying. *Food Chem* **303**:125386 (2020).

124 Pérez-Won M, Lemus-Mondaca R, Tabilo-Munizaga G, Pizarro S, Noma S, Igura N and Shimoda M, Modelling of red abalone (Haliotis rufescens) slices drying process: Effect of osmotic dehydration under high pressure as a pretreatment. *Innovative Food Sci Emerg Technol* **34**:127–134 (2016).

125 Zhang L, Liao L, Qiao Y, Wang C, Shi D, An K and Hu J, Effects of ultra-high pressure and ultrasound pretreatments on properties of strawberry chips prepared by vacuum-freeze drying. *Food Chem* **303**: 125386 (2020).
126 Cárcel J, Garcia-Perez J, Riera E and Mulet A, Improvement of convective drying of carrot by applying power ultrasound—Influence of mass load density. *Drying Technol* **29**:174–182 (2011).
127 do Nascimento EM, Mulet A, Ascheri JLR, de Carvalho CWP and Cárcel JA, Effects of high-intensity ultrasound on drying kinetics and antioxidant properties of passion fruit peel. *J Food Eng* **170**: 108–118 (2016).
128 Osae R, Essilfie G, Alolga RN, Bonah E, Ma H, and Zhou C, Drying of ginger slices—Evaluation of quality attributes, energy consumption, and kinetics study. *J Food Process Eng*:e13348,2019;
129 Gamboa-Santos J, Montilla A, Cárcel JA, Villamiel M and Garcia-Perez JV, Air-borne ultrasound application in the convective drying of strawberry. *J Food Eng* **128**:132–139 (2014).
130 Jin W, Zhang M and Shi W, Evaluation of ultrasound pretreatment and drying methods on selected quality attributes of bitter melon (Momordica charantia L.). *Drying Technol* **37**:387–396 (2019)
131 Bozkir H, Ergün AR, Tekgül Y and Baysal T. Ultrasound as pretreatment for drying garlic slices in microwave and convective dryer. *Food Sci Biotechnol* **28**:347–354 (2019).
132 Zhao Y-Y, Yi J-Y, Bi J-F, Chen Q-Q, Zhou M and Zhang B, Improving of texture and rehydration properties by ultrasound pretreatment for infrared-dried shiitake mushroom slices. *Drying Technol* **37**:352–362 (2019).
133 Tüfekçi S and Özkal SG. Enhancement of drying and rehydration characteristics of okra by ultrasound pre-treatment application. *Heat and Mass Transfer* **53**:2279–2286 (2017).
134 Wang R, Wang T, Zheng Q, Hu X, Zhang Y and Liao X, Effects of high hydrostatic pressure on color of spinach puree and related properties. *J Sci Food Agr* **92**:1417–1423 (2012).
135 Liu Y, Hu X, Zhao X and Song H, Combined effect of high pressure carbon dioxide and mild heat treatment on overall quality parameters of watermelon juice. *Innovative Food Sci Emerg Technol* **13**:112–119 (2012).
136 Yamaguchi K, Kato T, Noma S, Igura N, and and Shimoda M, The Effects of High Hydrostatic Pressure Treatment on the Flavor and Color of Grated Ginger. *Biosci Biotech Bioch* **74**(10):1981–1986 (2010).
137 Zhan L, Li Y, Hu J, Pang L and Fan H, Browning inhibition and quality preservation of fresh-cut romaine lettuce exposed to high intensity light. *Innovative Food Sci Emerg Technol* **14**:70–76 (2012).
138 Iizuka T, Maeda S and Shimizu A, Removal of pesticide residue in cherry tomato by hydrostatic pressure. *J Food Eng* **116**:796–800 (2013).
139 Qin Z, Guo X, Lin Y, Chen J, Liao X, Hu X and Wu J, Effects of high hydrostatic pressure on physicochemical and functional properties of walnut (Juglans regia L.) protein isolate. *J Sci Food Agr* **93**:1105–1111 (2013).
140 Li W, Bai Y, Mousaa SA, Zhang Q and Shen Q, Effect of high hydrostatic pressure on physicochemical and structural properties of rice starch. *Food Bioprocess Technol* **5**:2233–2241 (2012).
141 Verma D, Kaushik N and Rao PS, Application of high hydrostatic pressure as a pretreatment for osmotic dehydration of banana slices (Musa cavendishii) finish-dried by dehumidified air drying. *Food Bioprocess Technol* **7**:1281–1297 (2014).
142 Du YJ, Dou SQ, and Wu SJ, Efficacy of phytic acid as an inhibitor of enzymatic and non-enzymatic browning in apple juice. *Food Chem*, **135**(2):580–582 (2012).
143 Grimm E, Khanal BP, Winkler A, Knoche M, and Koepcke D, Structural and physiological changes associated with the skin spot disorder in apple. *Postharvest Biol Technol* **64**(1):111–118 (2012).
144 Grimm E, Khanal BP, Winkler A, Knoche M, and Koepcke D, Structural and physiological changes associated with the skin spot disorder in apple. *Postharvest Biol Technol* **64**(1):111–118 (2012).
145 Mao LC, Jeong JW, Que F, and Huber DJ, Physiological properties of fresh-cut watermelon (Citrullus lanatus) in response to 1methylcyclopropene and post-processing calcium applications. *J Sci Food Agr* **86**(1):46–53 (2006).
146 Arias E, Lopez-Buesa P, and Oria R, Extension of fresh-cut "Blanquilla" pear (Pyrus communis L.) shelf-life by 1-MCP treatment after harvest. *Postharvest Biol Technol*, **54**(1): 53–58 (2009).
147 Barbagallo RN, Chisari M, and Caputa G, Effects of calcium citrate and ascorbate as inhibitors of browning and softening in minimally processed 'Birgah' eggplants. *Postharvest Biol Technol*, **73**:107–114 (2012).
148 Amodio ML, Cabezas-Serrano AB, Peri G, and Colelli G, Postcutting quality changes of fresh-cut artichokes treated with different anti-browning agents as evaluated by image analysis. *Postharvest Biol Technol*, **62**(2):213–220 (2011).
149 Khunpon B, Uthaibutra J, Faiyue B, and Saengnil K, Reduction of enzymatic browning of harvested 'Daw' longan exocarp by sodium chlorite. *Scienceasia*, **37**(3):234–239 (2011).
150 Jiang T, Zheng X, Li J, Jing G, Cai L, and Ying T, Integrated application of nitric oxide and modified atmosphere packaging to improve quality retention of button mushroom (Agaricus bisporus). *Food Chem* **126**(4):1693–1699 (2011).
151 Barani YH, Zhang M, Wang B and Devahastin S, Influences of four pretreatments on anthocyanins content, color and flavor characteristics of hot-air dried rose flower. *Drying Technol*:1–8 (2019).
152 Agbidinoukoun A, Ahanhanzo C, Adoukonou-Sagbadja H, Adjassa M, Djikpo-Tchibozo MA and Agbangla C, Impact of osmotic dehydration on the encapsulated apices survival of two yams (Dioscorea spp.) genotypes from Benin. *J Appl Bio* **65** (2013).
153 Odewole MM and Olaniyan AM, Effect of osmotic dehydration pretreatments on drying rate and post-drying quality attributes of red bell pepper (capsicum annuum). *Agricultural Engineering International: CIGR Journal* **18**:226–235 (2016).
154 Oms-Oliu G, Aguiló-Aguayo I, Martín-Belloso O and Soliva-Fortuny R, Effects of pulsed light treatments on quality and antioxidant properties of fresh-cut mushrooms (Agaricus bisporus). *Postharvest Biol Technol* **56**:216–222 (2010).
155 El Kantar S, Boussetta N, Lebovka N, Foucart F, Rajha HN, Maroun RG, Louka N and Vorobiev E, Pulsed electric field treatment of citrus fruits: Improvement of juice and polyphenols extraction. *Innovative Food Sci Emerg Technol* (2017).
156 Bot F, Verkerk R, Mastwijk H, Anese M, Fogliano V and Capuano E, The effect of pulsed electric fields on carotenoids bioaccessibility: The role of tomato matrix. *Food Chem* **240**:415–421 (2018).
157 Gachovska T, Cassada D, Subbiah J, Hanna M, Thippareddi H and Snow D, Enhanced anthocyanin extraction from red cabbage using pulsed electric field processing. *J Food Sci* **75**:E323–E329 (2010).
158 Roohinejad S, Everett DW and Oey I, Effect of pulsed electric field processing on carotenoid extractability of carrot purée. *Int J Food Sci Technol* **49**:2120–2127 (2014).
159 Luengo E, Álvarez I and Raso J, Improving carotenoid extraction from tomato waste by pulsed electric fields. *Frontiers in nutrition* **1**:12 (2014).
160 Zeng F, Gao Q-y, Han Z, Zeng X-a and Yu S-j, Structural properties and digestibility of pulsed electric field treated waxy rice starch. *Food Chem* **194**:1313–1319 (2016).
161 Hossain MB, Aguiló-Aguayo I, Lyng JG, Brunton NP and Rai DK, Effect of pulsed electric field and pulsed light pre-treatment on the extraction of steroidal alkaloids from potato peels. *Innovative Food Sci Emerg Technol* **29**:9–14 (2015).
162 Segovia FJ, Luengo E, Corral-Pérez JJ, Raso J and Almajano MP, Improvements in the aqueous extraction of polyphenols from borage (Borago officinalis L.) leaves by pulsed electric fields: Pulsed electric fields (PEF) applications. *Industrial Crops and Products* **65**: 390–396 (2015).