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Chemical and physical pretreatments of fruits and vegetables: Effects on drying characteristics and quality attributes – a comprehensive review

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ABSTRACT
Pretreatment is widely used before drying of agro-products to inactivate enzymes, enhance drying process and improve quality of dried products. In current work, the influence of various pretreatments on drying characteristics and quality attributes of fruits and vegetables is summarized. They include chemical solution (hyperosmotic, alkali, sulfite and acid, etc.) and gas (sulfur dioxide, carbon dioxide and ozone) treatments, thermal blanching (hot water, steam, super heated steam impingement, ohmic and microwave heating, etc), and non-thermal process (ultrasound, freezing, pulsed electric field, and high hydrostatic pressure, etc). Chemical pretreatments effectively enhance drying kinetics, meanwhile, it causes soluble nutrients losing, trigger food safety issues by chemical residual. Conventional hot water blanching has significant effect on inactivating various undesirable enzymatic reactions, destroying microorganisms, and softening the texture, as well as facilitating drying rate. However, it induces undesirable quality of products, e.g., loss of texture, soluble nutrients, pigment and aroma. Novel blanching treatments, such as high-humidity hot air impingement blanching, microwave and ohmic heat blanching can reduce the nutrition loss and are more efficient. Non-thermal technologies can be a better alternative to thermal blanching to overcome these drawbacks, and more fundamental researches are needed for better design and scale up.

KEYWORDS
Pretreatment; drying; dipping; thermal blanching; non-thermal pretreatment

1. Introduction

As incomes and urbanization increased, global food-consumption dietary is transferring to protein-rich Western diets, higher in meats, refined sugars, fats and oils (Popkin et al., 2012). The global dietary shifts are threatening human health, environmental sustainability, and biodiversity (Tilman & Clark, 2014). While increasing fruits and vegetables consumption can mitigate this problem as they provide substantial health benefits and reduce global agricultural greenhouse gas emissions, reduce deforestation and can help prevent many diet-related chronic diseases, such as obese, type II diabetes, coronary heart disease and some cancers (Westhoek et al., 2014; Stehfest, 2014).

Fresh fruits and vegetables are perishable and difficult to preserve due to their high moisture content and tender texture. Drying is one of the most common preservation methods for extending the shelf life of fruits and vegetables by reducing the water content to a level so as to prevent the growth and reproduction of microorganisms and to inactivate many of the moisture-mediated deteriorative reactions (Mujumdar, 2014; Omolola et al., 2017). Drying extensively reduces the weight and volume of vegetables and brings benefits, such as minimizing packing, storage, and transportation costs (Kamiloglu et al., 2016). In addition, drying agro-products into low water content provides new products patterns such as vegetable crisps with unique texture and physical properties.

Fruits and vegetables are usually subjected to physical or chemical pretreatment before drying to shorten the drying time, reduce the energy consumption and preserve the quality of products (Yu et al., 2017). The drying rate and quality of products do largely relate to the pretreatments carried out before drying process (Fernandes & Rodrigues, 2008).

Generally, agro-products drying is a time and energy consuming process, pretreatment effectively enhances drying process. Ultrasonic waves has been used to enhance mass transfer by creating microscopic channels in solid material through unique mechanical fluctuation and cavitation effect that make the moisture transport easier (Mothibe et al., 2010). Several studies have confirmed that ultrasonic wave pretreatment could increase the effective diffusivity of water in the plant tissues, and reduce drying time by 10%–30% (Azoubel et al., 2010; Çakmak et al., 2016; Fernandes & Rodrigues, 2008). Osmotic dehydration has been widely applied before drying to reduce the initial water content, and then decrease drying time and energy consumption of fruits and vegetables (Rodrigues & Fernandes, 2007a; Ruiz-López et al., 2010). Many kinds of fruits, such as grapes, plums, and blueberries, are coved by a layer wax on the skin, which impedes water diffusion through the

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peel. Dipping in chemical additive solution, such as sodium hydroxide, ethyl or methyl oleate emulsions dissolves the waxy layer, and consequently increases the drying rate (Bingol et al., 2012; Doymaz & Pala, 2005; Sacilik et al., 2006). Blanching enhances the drying rates due to structure softening and cell wall destruction, leading to lesser resistance to moisture movement during drying (Severini, et al., 2005; Leeratanarak et al., 2006), which reduced the drying time and energy consumption of sour cherry by 61.83%–74.73% and 43.35%–77.69%, respectively (Gazor et al., 2014).

Color is one of the most important quality attributes of foods as it is critical in the acceptance of food products by consumers. It underwent a serious deterioration during drying, largely caused by enzymatic and non-enzymatic browning. The fresh fruits and vegetables with high content of polyphenols, polyphenol oxidase (PPO) and peroxidase (POD) are prone to enzymatic browning. Non-enzymatic browning includes a wide number of reactions such as Maillard reaction, caramelisation, chemical oxidation of phenols, and maderisation (Manzocco et al., 2000). Thermal blanching, such as hot water, steam and microwave blanching, is widely applied to inactivate the enzymes responsible for unacceptable darkening and off-flavors, thus preserving products' color (Araújo et al., 2016; Bai et al., 2013; Severini et al., 2005). In addition, sulfuration pretreatment is one of the most frequently used methods for preventing browning, as it retards both enzymatic and non-enzymatic browning reactions (Li & Zhao, 2006; Miranda et al., 2009), improve the color of products (Ahmed et al., 2010 a & b; Davoodi et al., 2007). Furthermore, osmotic dehydration can improve the color of mango chips and banana slices, as the monosaccharide present in the plant tissue, which is a reactive substance for browning reaction, is leached out with simultaneous sucrose uptake during osmotic dehydration (Tabtiang et al., 2012; Zou et al., 2013).

Fruits and vegetables are excellent sources of antioxidant compounds such as vitamins (especially vitamins C and E), flavonoids and carotenoids, which are expected to offer protection against cardiovascular diseases, cancer and age-related degenerative transformations, as shown by epidemiological studies (Schieber et al., 2001). Pretreatments performed before drying are desired to enhance retention of the antioxidant compounds. For example, microwave blanching maintained the anthocyanin level of sweet potato (Liu et al., 2015), mitigated ascorbic acid degradation of green asparagus (Hong & Lu, 2012). Ultrasonic pretreatment preserved the phenolic compounds in mushroom (Çakmak et al., 2016). Pulsed electric fields pretreatment yielded greater retention of carotenoid pigments of red pepper (Won et al., 2014), inactivated ascorbic acid oxidase by thus to minimize vitamin C degradation of dried crystal radish (Liu et al., 2016). High hydrostatic pressure pretreatment showed an improvement of the antioxidant activity of the aloe (Vega-Gálvez et al., 2011). In addition, pretreatment also improve rehydration capacity and crispness of dried products (Hiranvarachat et al., 2011; Rastogi, 2012; Doymaz & Özdemir, 2014), and make for forming a uniform microstructure of tissues (Jiang et al., 2015).

In sum, proper pretreatments can reduce the initial water content, or modify the properties of tissue in some extent, thereby increasing the drying rate, improving the quality of material; and inhibit the bio-enzymes, then minimize possible deterioration reactions during drying and subsequent storage. Therefore, the objectives of this review were to present an overview of the advances in pretreatment technologies (Fig. 1) of fruits and vegetables before drying, and evaluate the effects of different pretreatments on drying characteristics and quality attributes of products, as well as discuss the future research opportunities.

2. Chemical pretreatments

2.1 Liquid phase

2.1.1 Hyperosmotic solution

Osmotic dehydration is one of the most widely practiced pretreatments prior to drying to reduce energy consumption and improve food quality (Torreggiani, 1993). It involves the immersion of material in hypertonic solution (mainly sugar or salt) for several hours. During osmotic pretreatment, plant cellular structure acts as a semi-permeable membrane, countercurrent transfer of mass occurs: the solute flows into the products, while moisture is transferred from the interior to the hypertonic solution (Ciurzyńska et al., 2016), as shown in Fig. 2. The driving force of water removal from food material to the osmotic solution is the osmotic pressure difference between food material and the hypertonic solution (Corzo & Gomez, 2004).

Osmotic dehydration removes 10%–70% of water from fruits and vegetables at ambient temperature without causing phase changes, which offers an alternative way to reduce drying time, and mitigate degradation of bioactive compounds from thermal effects of drying (Ciurzyńska et al., 2016; Rastogi et al., 2002), as shown in Table 1. For example, Rodrigues & Fernandes (2007a) found that osmotic dehydration pretreatment with sucrose and mannitol reduced the drying time up to 6.3 h compared to un-pretreated samples. Ghosh et al. (2006) observed that the carrot slices pretreated with osmotic dehydration and then dried in hot air, obtained a better acceptability of color, appearance and odor compared to the control samples.

During osmotic processing, besides of properties of the material, the rate of mass transfer were greatly influenced by the process conditions, such as processing temperature, concentration of solution, solution to solid mass ratio, and etc. (Ahmed et al., 2016).

Increasing the concentration of solution, generally leads to an increase in the water mass transfer coefficient between the material and the solution owns to the increase in the osmotic pressure gradient. Ruiz-López et al. (2010) reported that, chayote parallelepipeds pretreated with 10% and 25% NaCl solutions (w/w), produced reduction in the initial moisture content of 2.85 and 5.79 kg/kg (db), in drying time of 48.0% and 62.1%, respectively. Similar results were reported by Oliveira et al. (2016) and Brochier et al. (2015) for yacon dehydration. However, the sucrose in excess may increase the viscosity of solution, which may generate an additional resistance for the mass enter the fruit. Teles et al. (2006) found that the mass transfer coefficient for 45%, 55% and 65% sucrose were 42.10, 23.99 and 20.73 h/m^2, respectively, confirmed the mass transfer coefficients were decreased with the increase of osmotic solution

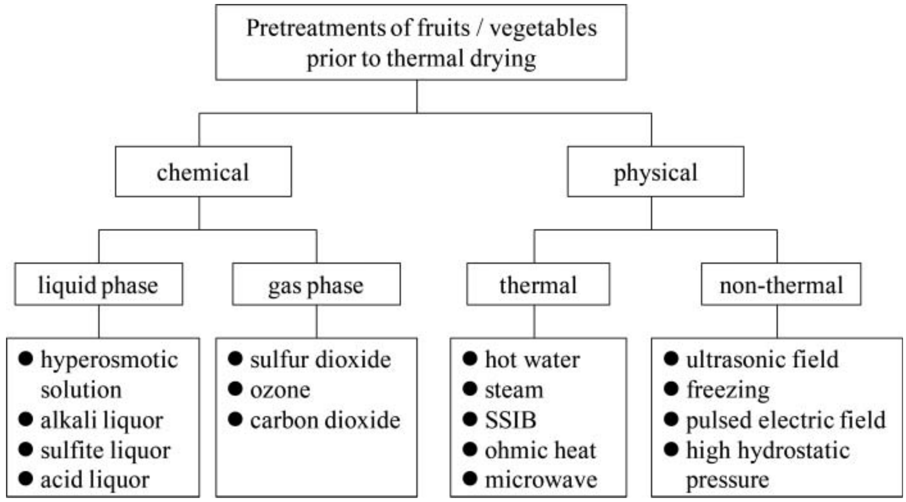

Figure 1. Pretreatment methods of fruits or vegetables prior to thermal drying.

concentration during osmotic dehydration of melons. Besides, in order to avoid formation of local concentration gradients, a constant mechanical agitation generally applied to homogenize the osmotic solution (Fan et al., 2008).

Moreover, the solution to solid mass ratio is an important factor, because of low values of this parameter may cause the excessive dilution of the osmotic solution, and then lead to local reduction of the osmotic driving force during the process. Teles et al. (2006) found that the water mass transfer coefficient between the melon fruits and the osmotic solution was higher for the weight ratio of osmotic solution to fruit was 4:1 than that of 2:1. Similar results were observed by Valdez-Fragoso et al. (2007) for dehydration of pepper. Oliveira et al. (2016) used a brine to sample ratio at least 25:1 during dehydration of yacon slices, to avoid significant dilution of the solution by water removal, however, it needs a great amount of solution.

Furthermore, the type of osmotic substance had significant effect on the mass diffusion coefficients, since the smaller molecular size enables its greater mobility in food (Oliveira et al., 2016). The mass loss rate of yacon treated with sorbitol solution was lowered than the glycerol, attributed to the sorbitol (molar mass = 182.17 g/mol) has lower permeability in the food matrix than glycerol (molar mass = 92.09 g/mol) (Brochier et al., 2015).

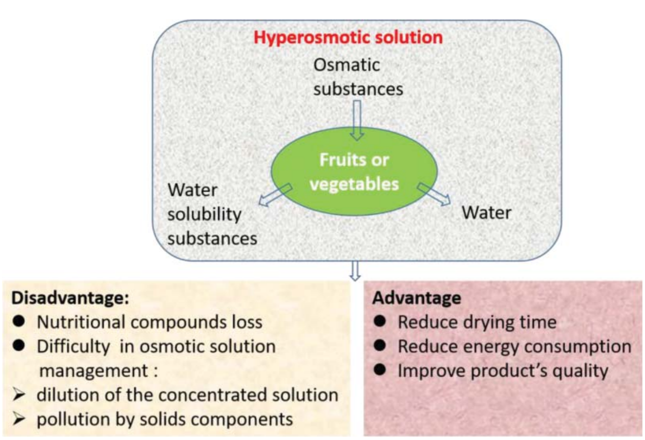

Figure 2. Osmotic dehydration of vegetables or fruits.

Additionally, increasing the temperature generally reduces the solution viscosity, gives rise to a higher membrane permeability, and then reducing the external resistance to mass transfer (Oliveira et al., 2016). Brochier et al. (2015) found that, increase of temperature caused a significant increase in effective diffusivity during osmotic dehydration of yacon. However, high temperatures may cause deterioration in texture and nutrition of the food (Brochier et al., 2015; Mercali et al., 2011).

Besides, combined with other techniques, such as vacuum, ultrasound and hydrostatic pressure, can enhance the mass transfer rate and quality of dried products (Valdez-Fragoso et al., 2007; Chandra & Kumari, 2015; Ciurzyńska et al., 2016). For example, osmotic dehydration combined with vacuum can increase the dehydration process and prevent discoloration caused by oxidative and enzymatic browning of fruits without loss of antioxidants as the oxygen was expelled from the environment (Zhao & Xie, 2004). Moreno et al. (2004) and Deng & Zhao (2008) observed similar phenomenon in osmotic dehydration of papaya and apple, respectively.

However, osmotic dehydration also has adverse effects on the drying rate of some products, attributes to the increased resistance to water flux caused by shrinkage and solutes uptake (Nieto et al., 2001). Azoubel et al. (2009) and Nieto et al. (2001) observed that, the drying rates of osmotic cashew apple and mangos decreased, which aggravated by the increase of glucose concentration. Moreover, osmotic dehydration caused a loss of low molecular weight substances migrating from tissue into osmotic solution, i.e., minerals, vitamins and pigments (Ciurzyńska et al., 2016). Azoubel et al. (2009) found that, osmotic pretreated cashew apple showed the vitamin C losses of 18.7% due to the leaching of vitamin C from the product to the osmotic solution. Novaković et al. (2011) also observed that the phenolic compounds and antioxidant activity of raspberry were decreased after osmotic dehydration. Meanwhile, osmotic dehydration pretreatment caused decrease of the hardness and increase of the darkness of dried mandarin product (Pattanapa et al., 2010).

In summary, though osmotic dehydration was often considered as a good energy saving method for the partial non-evaporating removal of water from foods, but there are also some

Table 1. Effects of chemical solution pretreatments on drying characteristics and quality attributes of fruits and vegetables.

Methods	Product	Pretreatment process	Drying methods	Main conclusion	Reference
Osmotic solution	Chayote	Dipped in 25% (w/w) NaCl at 25°C for 3 h, solution to fruit mass ratio of 4:1.	Hot air drying	Initial moisture content decreased by 17%, drying time reduced by 20–65%.	Ruiz-López et al., 2010
	Mellon	Dipped in 70°Brix sucrose at 42.5°C for 1h, solution to fruit mass ratio of 4:1.	Hot air drying	Cells breakdown, effective water diffusivity increased, drying time decreased by 20%.	Fan et al., 2008
		Dipped in an osmotic solution with sugar (70% w/w) and salt (5% w/w) at 42.5°C.	Hot air drying	A 455% increase in the water mass transfer coefficient, total processing time decreased.	Rodrigues & Fernandes, 2006
	Potato	Pretreated with salt solution (5, 10, 15% w/w) or sucrose solution (30, 40, 50% w/w) at 20°C for 6 h.	Microwave freeze-drying	Initial moisture content reduced up to 32% – 72% after OD; about 35%–65% reduction in drying time, 76%–676% increase in hardness and 42%–558% increase in crispness when OD used.	Wang et al., 2010
	Carrot	Dipped in sugar solution (50°Brix) containing 5% salt concentration and 0.1 sodium metabisulphite for 1 h.	Hot-air drying	Improved organoleptic characteristics with higher scores at 5%, dehydrated carrots slices had a higher rehydration ratio of 3.3.	Ghosh et al., 2006
	Pineapple	Dipping in sugar concentration (40, 50, and 60°Brix), immersion time (0, 3, and 6 hours).	Microwave drying	Preserved the color, reduced shrinkage, improved rehydration capacity, and softened the texture of sample.	Corrêa et al., 2011
	Apple	Dipping in 52% (w/w) sucrose / corn syrup solutions, fruit / solution ratio of 1:10, at 34°C for 165 min.	Fixed bed drying	Drying rates decreased, caused a great loss of vitamin C.	Azoubel et al., 2009
	Mango	Immersed into 22.1% and 39.5% (w/w) cerelose aqueous solutions, syrup-fruit weight ratio of 32:1, with agitation at 25 °C.	Hot air drying	Osmotic dehydration adversely influenced drying rate, the increase in glucose concentration caused decreased the D_{eff}.	Nieto et al., 2001
	Mandarin	Immersed in osmotic solutions containing 60% sucrose and 60% glycerol (9:1, 8:2, 7:3, 6:4 and 5:5 w/w, respectively) at 55°C.	Hot air drying	An increase in the glycerol ratio in the mixtures caused a significant decrease in hardness, and increased the darkness of the product.	Pattanapa et al., 2010
	Tomato	Dipped in either salt (0%, 10%, 15%, 20%) for 0, 2.5, 5.0, and 7.5 min.	Sun drying	Tomatoes dipped in salt solutions had lower rehydration ratios, did not improve the color of product.	Latapi & Barrett, 2006
Alkali liquor	Plums	Dipped into alkali emulsion contained K_2CO_3 (5%, v/v) and ethyl oleate (2%, v/v), at room temperature for 1 min.	Hot-air drying	Increased the drying rates, and drying time of pretreated samples was 29.4% shorter than that of untreated samples.	Doymaz, 2004
		Dipped in 4% ethyl oleate, 1% KOH, 1% NaOH, or water, at 23 or 60 °C, for 1 min.	Solar and open sun drying	Treated by 1% KOH or 1% NaOH at 60 °C were the fastest ones reaching to the final weight loss percentage, with slight variations in prune colors.	Tarhan, 2007
	Berry	Dipped in 0.1% NaOH solution with fruit to solution ratio of 1:1 (w/v) at 93 °C for 5 s.	Infrared radiation drying	NaOH pretreatment increased drying rate and moisture diffusivity and reduced the number of broken berries.	Shi et al., 2008
	Grape	Dipped in NaOH solution of 10, 20, 45, 70, or 80 g/L, for 10, 61, 185, 309, or 360 s.	Hot air drying	The use of relatively low sodium hydroxide contents increased the dehydration rate.	Corona et al., 2016
		Dipped in 2% ethyl oleate plus 2.5% K_2CO_3, 2.5% KOH or 2.5% Na_2CO_3, for 1 min.	Hot air drying	Reduced the drying time by 49%–57%.	Doymaz, 2006
	Gold cherry	Dipped in 2% ethyl oleate + 4% K_2CO_3, at 25°C for 1 min.	Hot air drying	Drying times for 15% final moisture were reduced by 3%–15%.	Ozdemir et al., 2016
	Sour cherry	Pretreated with 2% ethyl oleate + 5% K_2CO_3, for 1 min.	Hot air drying	Drying time was reduced by 26%–30%.	Doymaz, 2007
	Ginger	Dipped in 2% ethyl oleate + 5% K_2CO_3, for 1min.	Hot air drying	The drying time decreased, rehydration capacity increased.	Deshmukh, 2013
	Tomato	Dipped in 2% ethyl oleate + 3% K_2CO_3, for 1 min.	Hot air drying	Reduced drying time, increased rehydration ratio.	Doymaz & Özdemir, 2014

Sulfite solution	Mushroom	Dipping in sodium metabisulphite solution (1 or 5 g/L) for 10 min.	Hot air drying	Facilitated drying process, enhanced rehydration capacity and improved attractiveness of dried product.	Martínez-Soto et al., 2007
	Apples, bananas, carrots	Immersing in 2% sodium bisulfite solution for 5 minutes.	Convective drying	Prevented enzymatic browning reactions, color parameters (L, a, b) experienced only a small increase.	Krokida, et al., 2000
	Apricot	Treated with potassium metabisulphite (KMS) at concentrations of 2%–8% for 30, 45 and 60 min.	Solar tunnel-drying and open air drying	KMS pretreatment at concentration of 6% for 60 min helped in maintaining the quality (higher total carotenoids and ascorbic acid, lower non-enzymatic browning) of dried apricots for up to 12 months of ambient storage.	Mir et al., 2009
	Tomato	Dipped in sodium metabisulfite (0%, 4%, 6%, 8%) for 0, 2.5, 5.0, and 7.5 min.	Sun drying	Prevented color degradation during drying, especially by 6% or 8% sodium metabisulfite for 5 min; increased rehydration ratio; decreased yeast growth.	Latapi & Barrett, 2006
	Sweet potato	Dipped in 1% (w/v) $NaHSO_3$ at room temperature for 1 min.	Hot air drying, freeze drying	Maintained higher lightness, maintain ascorbic acid and β-carotene content.	Ahmed et al., 2010b
	Peach	Blanching (50 °C for 2 min) with 1% KMS	Hot air drying	Shortened drying time, increased the D_{eff} of peach slices	Kingsly et al., 2007
	Strawberry	Soaked in 2% sodium metabisulphite at room temperature for 2 min.	Sun drying	Improved rehydration ratio, acceptability of dried products	El-Beltagy et al., 2007
Acid solution	Carrot	Blanching in boiling 0.7% (w/v) citric acid (to obtain the pH of carrot of either 4 or 5.	Hot air drying	Enhanced drying rate, rehydration capabilities, and produced dried carrots with preferable redder color.	Hiranvarachat et al., 2011
	Tomato	Pretreated with solution of citric acid (1:25, w/w) at 20±1 °C for 1 min.	Hot air drying	Increased water diffusivity, reduced drying time, and improved rehydration ratio.	Doymaz, 2014
	Quince	Pretreated with citric acid (1:25, w/w) at 20±1 °C for 1 min.	Hot air drying	Reduced drying time more than 16%	Doymaz et al., 2015
	Sweet potatoes	Immersed in KMS and citric acid solutions in the following concentrations for 30 min: (a) 0.5:0.5% (b) 0.5:1.0% (c) 1.0:0.5% (d) 1.0:1.0%	Hot air drying	The slices treated with 1.0% KMS and 1.0% citric acid at 50 °C provided better color and would need less energy for drying.	Singh et al., 2006
	Apple	Dipped in solutions with various combinations of ascorbic acid (AA), citric acid (CA) and calcium chloride (CC) at different concentrations (0.1–1.5%) for up to 10 min.	Infrared dry-blanching	The combination of any two chemicals among CA (0.2–0.4%), AA (0.5%–1.5%) and CC (0.1–1%) was effective to slow down enzymatic browning rate, preserving the surface color of apple cubes.	Zhu et al., 2007
		Dipped in 0.5% citric acid at room temperature for 2 min.	Hot air drying	Shortened drying time, increased the D_{eff} of apple slices.	Doymaz, 2010
	Peach	Blanching (50 °C for 2 min) with 1% ascorbic acid.	Hot air drying	Shortened drying time, increased the D_{eff} of peach slices.	Kingsly et al., 2007
	Banana	Dipped in a solution containing 10 g/L ascorbic acid and 10 g/L citric acid for 1 min.	Freeze drying	Improved product color, reduced freeze-drying time and shrinkage.	Pan et al., 2008
	Kidney bean seeds	Dipped in citric acid (1:200, w/w) at 20±1 °C for 1 min.	Hot air drying	Shortened drying time up to 26.66% when dried at 50 °C.	Doymaz, 2015

limitations to application of the osmotic dehydration as noted above, especially changes related to leaching from the product (color, acids, sugar, minerals, vitamins, etc.) should not be neglected. Additionally, during osmotic dehydration, the most important change is dilution of the concentrated solution, and solution recycle caused additional processing step, especially mixed solutes as it is more complex to adjust (Raoult-Wack, 1994). It also observed that as osmotic pretreatment proceeds, turbidity, browning, content of insoluble solids as well as microbial load in the osmotic solution increase gradually, therefore, the recycle and management of a large amount of osmotic solution is a tough issue, which must be paid more attention (Ciurzyńska et al., 2016).

2.1.2 Alkaline liquor

The alkaline dipping pretreatment is primarily used for whole berry fruits, whose outer skin is covered by hydrophobic wax. The wax coating consists largely of oleanolic acid, lead to a low rate of moisture evaporation during drying, it presents as an obstacle to drying (Serratosa et al., 2008). Dipping of berries into alkaline emulsions of ethyl or methyl esters, sodium hydroxide, and potassium carbonate for several minutes can dissolve the wax layer, or destroy the microstructure in the epicuticular wax layer (Bingol et al., 2012; Doymaz & Pala, 2002), or even breakdown of intracellular bonding through de-esterification of pectin (Esmaiili et al., 2007). And then enhance the permeability of the skin to moisture, facilitate moisture diffusion and increase the dehydration rate (Corona et al., 2016; Doymaz & Altıner, 2012).

Alkali liquor dipping pretreatment accelerates the drying rate and reduces the drying time, consequently decrease the deterioration of quality of products, as listed in Table 1. Bingol et al. (2012) showed that alkali dipping pretreatment (potassium carbonate and ethyl oleate solutions at 60 °C for 2 and 3 min), improved the lightness (L^* values) of dried grapes by 37%– 55%. The finding was similar to the reports by Doymaz & Pala (2002) and Doymaz & Altıner (2012) for grapes. In terms of color-preserving of dipping treatment, the alkaline emulsions might either suppress the activity of PPO or increase drying rates, consequently enhances the sugar concentrations close to the skin and therefore lowers the water activity, which in turns slow down the browning reaction (Grncarevic & Hawker, 2010).

The drying process accelerated by alkali dipping of berries was influenced by the composition of chemical agents, concentration, pH, temperature, and the dipping time (Esmaiili et al., 2007). The drying time to obtain a same moisture content of grapes pretreated with potassium carbonate plus ethyl oleate was shorter than that in potassium carbonate plus olive oil, indicated organic component of the dipping agent was more influential than potassium carbonate for grape pretreatment. It was consistent with results by Doymaz & Pala (2002) and Doymaz (2006). However, Tarhan (2007) observed that, ethyl oleate solution had slighter accelerated drying process of plums, while both KOH solution and NaOH solution significantly enhanced weight loss rate, it may own to the variety difference between grape and plum. Bingol et al. (2012) reported that, the drying rate of grape increased with the temperature of the dipping solution increased, and samples dipped for longer times obtained lower drying time, such as the dipping time at 30 and 40°C for 3 min reduced the drying time by 11 and 5 h, respectively, compared to 2 min dipping. Similar results were reported by Tarhan (2007) for plums treated at 60°C showed higher weight loss rate than that at 23°C. However, when dipping temperature at 50 and 60°C, there were no significant difference of drying time between grapes dipping for 2 and 3 min (Bingol et al., 2012).

While alkaline liquor dipping pretreatment also has limitations. Alkali dipping pretreatment may lead a leaching, degradation and oxidation of ascorbic acid, owns to alkaline media and effects of oxygen caused by micro-crack of epidermis. Vásquez-Parra et al. (2014) found that, NaOH, olive oil and K_2CO_3 pretreatments significantly decreased the content of vitamin C of dried cape gooseberries (ranging from 0.26 to 0.46 mg/g db.) relative to the untreated (more than 0.55 mg/g db.). In addition, the residue of alkaline liquor in the dried products may trigger food safety issues, and do harm to human's health. So alkaline liquor dipping technology should be applied only if a major drying time reduction is needed (Carranza-Concha et al., 2012).

2.1.3 Sulfite solution

Sulfitation or sulfuring has been widely used in the food industry to reduce darkening during drying and prevent quality loss during process and storage of foods (Miranda et al., 2009). It is usually performed using sulfur dioxide gas or water-soluble sulfide salts such as potassium metabisulfite ($K_2S_2O_5$), sodium metabisulfite ($Na_2S_2O_5$) and sodium hydrogen sulfite ($NaHSO_3$). When SO_2 is absorbed into the fruit, it is converted mainly to the bisulphate ion. Both enzymatic and non-enzymatic browning and microbial activity are prevented by using sulfites at low concentration (Joslyn & Braverman, 1954). Sulfite inactivates PPO through the reaction between sulfite ions and quinines, by thus to inhibit of PPO activity and deplete of oxygen (Van Hal, 2000). It also acts as an antioxidant in preventing loss of ascorbic acid and protecting lipids, essential oils, and carotenoids against oxidative deterioration during processing, and it has the advantages of maintaining color, preventing spoilage, and preserving certain nutritive attributes (Mujumdar, 2006).

Sulfitation treatment has been widely used to improve quality (color, rehydration ratio, β-carotene content, and etc.) of agro-products, such as apricot, tomato, apple, banana, potato and carrot (Krokida et al., 2000; Latapi & Barrett, 2006; Mir et al., 2009; El-Beltagy et al., 2007), as illustrated in Table 1. Meanwhile, sulfitation facilitates drying through changing the cell membranes permeability of fruits and vegetables (Lewicki, 1998). Peaches pretreated with 1% potassium meta bisulphate, the drying rate and D_{eff} were incresed by 12.5%–14.3% and 13.2%–15.5% compared to the untreated one (Kingsly et al., 2007). Karabulut et al. (2007) found that, sulfuring pretreatment reduced the drying time of apricots by 3.6%–38.64%, and the L^* values of dried product increased, as compared to non-sulphurated one. Mir et al. (2009) observed that, apricots pretreated with $K_2S_2O_5$ solution had higher retention ratio of ascorbic acid and carotenoids.

There are various processing factors affects the uptake of sulfites, such as performed forms (gas or solution), the concentration of solution, processing time, and the pH of the soak liquor. For example, the extent of non-enzymatic browning of apricots was decreased with the increase of dipping time and concentration of potassium meta-bisulphite solution (Mir et al., 2009). Notably, pretreatment of vegetables and fruits with sulfur dioxide gas is impractical, by contrast, sulfite solutions are preferred as the most practical method of controlling absorption (Jayaraman & Gupta, 2006).

Although sulfite pretreatment has marked effects on maintaining color of products, but it also causes a loss of some water-soluble nutritional compounds, creates undesirable flavor and soft texture. For example, metabisulfite pretreatment caused the total loss of ascorbic acid apricots by leaching from the fruit into the sulfite solution during the immersion treatment (Garcia-Martinez et al., 2013). Moreover, sulfite is being discarded and often forbidden by legislation. The most prominent problem of sulfite pretreatment is the chemical residue in the product, which can cause some health problems such as asthmatic reactions in some sensitive individuals (Güçlü et al., 2006; Kamiloglu et al., 2016; Taylor et al., 1986). New standards for food additives by the Ministry of Health of the People's Republic of China has increased the standard for use of sulphur treatments in food processing; the residue of sulfur dioxide, potassium metabisulphite, sodium metabisulphite, sodium sulphite in food products has been strictly limited to 0.2g/kg of dried vegetables, and 0.1 g/kg of dried fruits (Ministry of Health of the People's Republic of China, 2011). In addition, the Food and Drug Administration requires a label declaration on any food containing more than 10 ppm of sulfating agents since 1986, because of their alleged hazard to asthmatics (FDA 1986). As organic foods become increased popular, use of sulphite in food processing is being discouraged.

2.1.4 Acid liquor

Acid pretreatment also frequently used to improve the product quality through inactivating of enzymes, enhancing pigment stability and modifying texture of agro-products. The optimum pH of polyphenol oxidase lies within the range of 6.0–7.0, so the polyphenol oxidase activity can be inhibited when the media pH is lowered to 3.0, consequently, the rate of enzymatic browning decrease (Langdon, 1987). Moreover, the stability of pigments, such as betalains and anthocyanins, can be enhanced at acid condition (Ngamwonglumlert et al., 2016), and texture of product can be maintain by using acid solution, due to their chelating properties (Hiranvarachat et al., 2011).

Citric acid, as an organic acid, is the most commonly used as anti-darkening agent and a texture-modifier of fruits and vegetables. Meanwhile, it has been confirmed that citric acid can accelerate the drying process, as pectin loosening in acidic environment, in turns promoting water removal (Hiranvarachat et al., 2011). The effects of citric acid pretreatment on maintaining color and enhancing drying rate of fruits and vegetables, as summarized in Table 1, which was also influenced by the concentration of solution, dipping time and temperature. Zhu et al. (2007) reported that dipping time affect the L values of apple cubes, for instant, 5-min dipping showed a higher L value than 0.5- and 1-min dipping, attributed to long dipping treatments resulted in better penetration; meanwhile, the decrease in L value was reduced when acid solution concentration increased.

Additionally, ascorbic acid as an antioxidant has been used to pretreat agro-products before drying, as it can reduce the o-quinones to colorless dihydroxyphenols, and form a barrier to oxygen diffusion into the product (Santerre et al. 1988). Generally, the ascorbic acid is considered less effective in inhabiting enzymatic browning, attributes to its insufficient penetration into the cellular matrix, so it usually combined with citric acid. Zhu et al. (2007) found that combined ascorbic acid and citric acid was effective to slow down enzymatic browning rate of apple cubes. Doymaz (2010), Kingsly et al. (2007) and Pan et al. (2008) also confirmed that citric acid or ascorbic acid shortened drying time or improved product color of sweet potato slices, peach and banana, respectively.

In addition, acid dipping also involves in the loss of water soluble nutrients by leaching into dipping solution and degradation at acidic environment. For example, solid loss of apple cubes was up to 19.28% when dipped in ascorbic acid + citric acid for 10 min (Zhu et al., 2007). Besides, some pigments are sensitive to acids, such as chlorophylls and carotenoids, using acid solution may cause the pigments degradation and color change. For example, the chlorophylls are prone to be pheophytin at acidic condition, lead to the color changes from green to olive brown (Ngamwonglumlert et al., 2016). Acid soaking significantly reduced the β-carotene retention of carrots by 29%–61%, as compared to water soaked samples (Hiranvarachat et al., 2011).

2.2 Gas phase

2.2.1 Ozone

Ozone (O_3), highlights for its high oxidation potential (2.07 mV), generally used as a bactericide or fungicide, without residue after the decontamination process by decomposing into oxygen (Freitas-Silva & Souza, 2016). Ozone usually applied to inactivate various bacteria, including Gram-negative and Gram-positive vegetative and sporulated forms, as well as components of the cell envelope, spores, fungal, or viral capsids at relatively low concentrations and short contact times (Freitas-Silva and Venancio, 2010).

Recently, ozone has been applied to reduce pesticide residue of vegetables and fruits. Hwang et al. (2002) reported that ozone wash reduced the residues of mancozeb and ethylenethiourea in fresh apples and their products. Antos et al. (2013) treated blackcurrants with ozone before drying, the results showed that, the utilization of ozone in a gaseous phase permitted a 38% reduction of mancozeb residues, in comparison with the initial concentration. For this reason, it is important to develop efficient methods of food processing which would enable a reduction in the active ingredient residues. Nevertheless, ozone may cause undesirable effect, it may promote oxidative degradation of chemical constituents, causing loss of color, change in aromaticity, and mischaracterization of the initial quality of the food (Miller et al., 2013).

2.2.2 Carbon dioxide

Carbon dioxide (CO_2) pretreatment shows dominant advantages, because of its environment-friendliness and safety for food as well as quality. Its general application form is called carbonic maceration (CM) technique, invented by Michel Flanzy in 1934, it involves placing the samples into a closed tank with a carbon dioxide-rich atmosphere, this adaptation is reflected almost instantly inside plant materials by the transition from a respiratory to fermentative anaerobic metabolism (Tesniere & Flanzy, 2011). The CM results the fruits and vegetables occur under the rich CO_2 anaerobic conditions, the cytoplasm pH decrease, explosive cell rupture, modification of a cell's membrane, inactivation of key enzymes and extraction of intracellular substances, thus enhancing the drying rate (Gunes et al., 2005; Zhao et al. 2016). What's more, acidic environments with low pH value created by CM, and short drying time contributed to higher retention of nutritional components (Zhao et al. 2016).

CM technique has been used for the pretreatment of sweet potato, tomato and chili before drying, effectively enhanced drying process and improved quality of dried products. Zhao et al. (2016) confirmed that CM pretreatment reduced drying time of sweet potato by 38.1%–34.6%, the retention of phytochemicals (flavonoids, anthocyanin, total phenols, β-carotene contents and vitamin C) and DPPH radical scavenging activity of CM pretreatment samples were 13.83%–78.18% and 10.04%–14.09% higher than those of untreated, respectively. Liu et al. (2014) found that CM pretreatment (0.2 MPa, 30 °C, 30 h) accelerated the drying rate of chili by 50%–85%, increased the DPPH scavenging free radical capability, ferric reducing antioxidant power, total phenol contents and vitamin C retention contents of the dried products by 70.1%–90.9%, 40.2%–47.8%, 40.1%–60.0% and 112.7%–582.4%, as compared to those direct-drying samples, respectively. Liu et al. (2011) applied CM pretreatment (0.14 MPa, 36°C, 72 h) on grapes, the total phenol content and drying rate of fermented grapes increased by 48.3% and 44.6%, respectively, when compared with untreated grapes.

Nevertheless, CM pretreatment induces an amount of anaerobic respiration (Chen et al., 2017), consequently changes the texture and aroma of products. Turgut et al. (2017) verified that CM reduced the drying time of tomato quarters, while, the water activity and titratable acidity of CM pretreated samples were significantly increased, and texture were lower than control one. Chen et al. (2017) reported that CM caused an accumulation of acetaldehyde and ethanol, simultaneously changed the aroma composition of dried jujube products.

Therefore, the CM pretreatment technique has great potential for accelerating the drying process and enhancing the quality of dried products, as well as free of harmful chemical reagents residues. However, it usually involves in treating for 12 – 72 h, the low efficiency may hinder the application of CM. Meanwhile, the deterioration of texture and flavor of product may be unavoidable during CM pretreatment.

2.3 Other chemical pretreatment

Besides, there are also other pretreatments applied to foods before drying, e.g. $CaCl_2$, ethanol, edible coatings. Immersion in $CaCl_2$ can increase the concentration of Ca^{2+} in the cell wall and prevent the loss of firmness of plant tissues (Alonso et al., 1997). Vega-Gálvez et al. (2008) reported that red bell pepper pretreated by chemical solution containing $CaCl_2$, the cell wall did not rupture significantly after air-drying at 70 °C, a thickening of the cell wall was observed, which enhanced firmness more than twice of the dried sample. Zhao et al. (2016) reported that 15% ethanol dipping pretreatment not only reduced drying time by 51.61%, but also improved rehydration ratio and color attributes of dried products by 26.74% and 18.99%, compared to untreated samples, respectively. In addition, the application of edible coatings pretreatments may reduce the loss of aroma, color and nutrients by reducing oxygen diffusion into the food, minimizing solute incorporation and maintaining the integrity of product during drying (Oliveira et al., 2015). Lago-Vanzela et al. (2013) found that, starch coatings pretreatment, resulted in dehydrated pumpkin with better color and significantly higher retention of trans-α-carotene and trans-β-carotene than those without pretreatment. Liu et al. (2014) treated purple-fleshed sweet potatoes with a coating of sodium alginate for microwave-assisted spouted bed drying, and found the coating changes the dielectric properties of sweet potato cubes and shortens the drying time by 8–10 min.

In conclusion, although chemical pretreatments have advantages of enhancing drying process, maintaining quality of products, however, residual alkali liquor, sulfite/sulfur dioxide in foods causes food safety problems. As organic foods becoming more and more popular, using of chemical additives in foods is being discouraged (Dev et al., 2008). Moreover, disposal of larger quantities of waste solution with corrosive chemicals is a serious problem in practice as well. Furthermore, the water-soluble nutrients such as ascorbic acid, minerals, sugars, etc., flow out from the fruits into the solution during liquid phase immersion pretreatment is also an unignorable issue. Therefore, in order to improve the quality and safety of products, the traditional chemical additive pretreatment technique needs to be replaced by a more efficient, safe and controllable method.

3. Physical pretreatment

3.1 Thermal blanching

Thermal blanching is widely used prior to drying, its primary goal is to inactivate the enzymes involved in the spoilage of fresh agro-products, in addition to reduce the microbial load of products so as to improve its conservation, to soften tissues for facilitating drying process, and to eliminate intracellular air to prevent oxidation.

3.1.1 Conventional hot water blanching

Hot water blanching is a common pretreatment used prior to drying, it involves to immerse fresh products into hot water at a constant temperature ranging from 70 to 100 °C for several minutes (Guida et al., 2013). Generally, hot water blanching has been used to prevent quality deterioration by inactivating the enzymes, destroying microorganisms, or expelling intercellular air from the tissues (Mukherjee & Chattopadhyay, 2007; Neves et al., 2012; Xiao et al., 2012 & 2016). Meanwhile, it also helps to accelerate drying rate by changing the physical properties of the samples such as the permeability of the cell membranes (Jangam, 2011), dissociating the wax on and forming of fine cracks on the skin of products (Jayaraman & Gupta, 2006).

Currently, conventional hot water blanching is the most popular and commercially adopted method, because of its simple equipment and easy operation. It has been widely applied on pretreatment of agro-products to enhance the drying rate and improve the product quality (Doymaz, 2015; Filho et al., 2016; Cheng et al., 2015; Ando et al., 2016; Doymaz, 2014), such as summarized in Table 2.

During hot water blanching process, the marked deterioration in food quality is also implicated in oxidase inactivation, especially with the development of cooked off-flavors, color alteration and the loss of thermo-sensitive compounds (Benlloch-Tinoco et al., 2013). On the one hand, processing for agro-products with complete inactivation of oxidase is more than adequate to those with activity of peroxidase left, as the quality of the blanched products may be better than unblanched (Agüero et al., 2008). As confirmed by Lavelli et al. (2007), the content of α-Carotene, β-Carotene and Lutein in blanched carrots were 51%, 76% and 87% higher than non-blanched samples, due to the inactivation of peroxidase and lipoxidase activity. On the other hand, the considerable loss of soluble nutrient substance by dissolving or leaching into blanching water can't be neglected, such as sugars, proteins, carbohydrates, water-soluble minerals and vitamin (Garba et al., 2015; Mukherjee & Chattopadhyay, 2007). Furthermore, hot water blanching had negative influence on the texture and microstructure of sample, which aggravated the loss of soluble nutrient substance, even increased the drying time (Olivera et al., 2008; Dandamrongrak et al., 2003; Badwaik et al., 2015).

In addition, hot water blanching generates large quantity of waste water and increases the pollutant charge. So it is very tempting for food industry to use alternative means of thermal blanching such as steam blanching, high humidity hot air impingement blanching, ohmic blanching, and microwave blanching.

3.1.2 Steam blanching

To minimize nutrients especially the water-soluble nutrients and solid content dissolves into hot water and reduce the wastewater, steam blanching systems were developed to replace hot water blanching. It is believed that the steam blanching contributes to retention of most minerals and water-soluble components as compared with water blanching, due to its negligible leaching effect.

Compared to hot water blanching, steam blanching for equal treated time resulted in significantly higher ascorbic acid retention (Lin & Brewer, 2005). Lin & Brewer (2005) reported that, steam blanched peas had higher ascorbic acid content (22 mg/100 g) than water blanched peas (14 mg/100 g), slightly lower than non-blanched peas (29 mg/100 g). It was also confirmed by Gamboa-Santos et al. (2012), that steam blanching gave rise to carrots with higher retention of vitamin C (81.2%) than those blanched in water at 60 °C (1.3%). What's more, steam blanching can significantly inactivate the biological enzyme due to the high enthalpy contents. Steam blanching of 3 min gave low activities of 1.71% of PPO (Ndiaye et al., 2009), while, immediately pasteurized at 85 °C for 3 min, the PPO residual activity of mango pulp was about 50% (Vásquez-Caicedo et al., 2007). Besides of oxidase inactivation, steam blanching increased the content of phytochemicals content in samples by enhanced extraction of these components as a result of increased permeability of cellular membrane, such as phenols and ACNs in blueberries (Del et al., 2012).

However, during the steam blanching process, softening of the tissue and undesirable quality changes often result from long heating time due to the lower heat transfer in steam blanching especially when the velocity of the steam is very low. And during the early stage of steam blanching, steam condenses on the surface of the products, because of the product temperature lower than the steam, which may result in non-uniform blanching effects.

3.1.3 Superheated steam impingement blanching

With increasing in demand of high-quality products, it is very important to minimize nutrient loss during the pretreatment, the traditional hot water and steam blanching should be replaced by novel techniques. Superheated steam impingement blanching (SSIB), also called high humidity hot air impingement blanching (HHAIB), is a recently developed thermal treatment technology, which combines the advantages of superheated steam blanching and impingement technologies. SSIB has higher enthalpy, transfer heat rate and energy efficiency, the heat transfer coefficient of SSIB was about 1403 W/(m^2·K) with velocity of 14.4 m/s, temperature of 135 °C, and relative humidity of 35%, respectively, it is about 12 times of that of hot air impingement at the same temperature and velocity (Du et al., 2006). SSIB has advantages in a uniform, rapid and energy-efficient blanching, as well as better product quality retain (Specht, 2014; Xiao et al., 2014).

SSIB possesses an excellent capability of preventing browning and maintaining color by inactivating oxidase rapidly, increasing drying rate by modifying the skin and pulp tissue (Xiao et al., 2009 & 2012; Gao & Xiao, 2008). Recently, SSIB technology has been applied to several vegetables and fruits pretreatment, as illustrated in Table 2. Wang et al. (2017a) applied HHAIB processing (110 °C, RH 30%–40%, air velocity 14.0 $\pm$ 0.5 m/s) to red pepper, results showed that POD activity rapidly decreased to 7% after 120 s; the drying time for blanched samples were reduced by 17 h, as compared to non-blanched peppers. Bai et al. (2013a) observed that the SSIB completely inactivated PPO within 7 min at 90–120 °C of apple quarters with thickness of 38 cm, while infrared radiation at 4000 W/ m^2, fully inactivated PPO of 1.3 cm apple slices also needed 7min; the retention of vitamin C more than 11% when blanched at 90 °C for 7 min. Bai et al. (2013b) also reported that SSIB effectively inactivated PPO activity at 110 °C for 90s, reduced drying time by 12–25 h and improved color quality of seedless grapes, which presented as desirable green–yellow or green color.

SSIB technology is excellent of reducing time of oxidase inactivation and minimizing nutrient loss. And therefore, it will play an increasingly important role in agro-products processing. However, SSIB technology is still in its infancy, and further studies are needed to design and testing of large SSIB equipment for large-scale industrial operation, improve heating

Table 2. Effects of thermal blanching pretreatments on drying characteristics and quality attributes of fruits and vegetables.

Methods	Product	Pretreatment process	Drying method	Main conclusion	Reference
Hot water blanching	Kidney bean seeds	Immersed in hot water at 80±1 °C for 1 min.	Hot air drying	Pretreated sample with higher rehydration of 10%–20%.	Doymaz, 2015
	Pumpkin	Immersed in boiling water (98.3 °C) for 1 min.	Hot air drying	Increased evaporated water constant fluxes of 12.40%–23.76%, but reduced total sugar contents of 8.24%–14.86%.	Filho et al., 2016
	Cherry tomato	Blanched with hot water (90±1 °C) for 5 min.	Hot air drying	The D_{eff} varied in the range of 1.7281×10^{-9} to 4.6306×10^{-9} m^2 s^{-1} for the fresh sample, while 2.1034×10^{-9} to 6.6487×10^{-9} m^2 s^{-1} for the blanched sample.	Cheng et al., 2015
	Carrot	Immersed in hot water (60, 70, 80 or 100 °C) for 5 min.	Hot air drying	Drying rate was increased by more than 10%, capacitance of cell membrane and pectin methylesterase activities were decreased by more than and 16% and 60%, respectively.	Ando et al., 2016
	Banana	Blanched in boiling water for 3 min.	Heat pump drying	Increased drying rate by 8% and improved moisture diffusivity by 106%.	Dandamrongrak et al., 2002
	Quince	Immersed in hot water at 80 ± 1°C for 1 min.	Hot air drying	Decreased drying time more than 14%, and increased rehydration ratio.	Doymaz et al., 2015
	Pepper	Immersed in hot water at 75 °C for 180 s.	Hot air drying	Blanched pepper had higher initial drying rate (1.44 $kg \cdot kg^{-1} \cdot h^{-1}$) than in fresh pepper (0.84 $kg \cdot kg^{-1} \cdot h^{-1}$); the drying time was reduced by 19%.	Weil et al., 2017
	Asparagus	Placed in distilled water baths set at 70, 80 and 90 °C	No given	The retention of ascorbic acid lowered than 2%	Zheng & Lu, 2011
	Banana	Blanched in boiling water for 3 min.	Heat pump drying	Blanching failed to improve drying rate, even increased drying time.	Dandamrongrak et al., 2002
Steam blanching	Apple, banana, potato and carrot	Carried out by blowing steam for 2 min.	Conventional drying	Prevented enzymatic browning, improved color of products.	Krokida et al., 2000
	Galega kale	Blanched by water steam at 101, 325 Pa for 1 min.	Conventional drying	Improved color and appearance, reduced the degradation of vitamin C, antioxidant capacity and chlorophylls.	Araújo et al., 2016
	Cauliflower	A single layer of the cauliflower florets suspended above 400 g of boiling water for 10 min.	Without drying	Induced the least reductive effect on glucosinolates, total monomeric anthocyanins, total phenols, and antioxidant capacity, compared to hot water blanching and boiling treatment.	Volden et al., 2009
	Parsley leaves	Subjected to the steam blanching over the boiling water 99 ± 1 °C for 3 s (every time), and repeated four times.	Microwave- convective drying	Reduced the drying time maximally by 28.9%, decreased the specific energy consumption up to 28%, and increased the color stability.	Sledz et al., 2016
	Broccoli	Blanched for 30, 60, 90, 120 and 180 s respectively.	Hot air-drying	Rapidly inactivated peroxidase activity within 60 s, ascorbic acids losses less than hot water blanching.	Roy et al., 2009
Superheated steam impingement blanching (SSIB)	Yam	Blanched at 120 °C and 35% relative humidity for 3, 6, 9 and 12 min, respectively.	Air impingement drying	When blanching for 6 min, drying time was reduced by 35%, whiteness index was increased by 50%.	Xiao et al., 2012
	Sweet potato	Treated with 120 °C and 35% relative humidity for 3 and 5 min separately.	Air impingement drying	Increased drying time by 11% and 44%, but obtained a homogeneous compact structure, softer texture, and desirable color.	Xiao et al., 2009
	Sea cucumber	Blanched at 90–200°C for 5–40 min under relative humidity of 10%–50%, air velocity of 3–20m/s.	Air impingement drying	Autolytic enzyme was completely inactivated, the color and shape of the products were improved.	Gao & Xiao, 2008

	Apple	Sample was treated with four different temperatures: 90, 100, 110 and 120 °C, relative humidity was 40%–45%, and air velocity was 15.0 m/s.	Without drying	The time of PPO totally inactivated (38 cm quarters, 90 °C – 7 min, 100 °C – 6 min, 110 °C – 5 min, 120 °C – 5 min) was shorter than infrared (1.3 cm slices, 7min).	Bai et al., 2013a
	Seedless grape	Blanched at different temperatures (90, 100, 110, and 120 °C) and durations (30, 60, 90, and 120 s).	Air impingement drying	Drying times reduced by 12–25 h at drying temperatures of 55–75 °C, significantly inhibited enzymatic browning and yielded desirable green–yellow or green raisins, when blanching at 110 °C for 90s.	Bai et al., 2013b
	Red pepper	Blanched at 110 °C for 1, 2 and 3 min, with air velocity of 14.0 ± 0.5 m/s	Air impingement drying	SSIB maintained higher retention of red pigments and ascorbic acid, and values of antioxidant activity compared to samples blanched by hot water; reduced drying time up to 4.0 h compared to untreated ones.	Wang et al., 2017a
		Air velocity 14.0 ± 0.5 m/s, temperature 110 °C, hot air relative humidity 35% – 40%, and several durations (30, 60, 90, 120, 150, 180, 210, and 240 s).	Air impingement drying	POD residual activity was decreased to 7% after 120 s, drying time for samples blanched for 30, 60, 90, 120, 150, 180 s was reduced by 1, 3, 5, 7, 4, and 3 h, respectively; but over blanching (210 s and 240 s) caused red pigment loss (13% and 26%) and drying time increasing (56% and 86%).	Wang et al., 2017b
Ohmic heat blanching	Artichoke	Field strength of 14 V/cm, when the core of the sample reached to 80 ± 2 °C, samples were maintained for 0, 60, 120, 180, 240 or 300 s.	Without drying	Inactivated both PPO and POD at shorter processing times than conventional blanching; the color, protein and polyphenol content of the product were well preserved.	Guida et al., 2013
		Ohmic blanching (25 and 40 V/cm at 85°C) and water blanching (at 85 and 100 °C).	Fluid bed drying	Both ohmic and water blanching rapidly inactivated POD, vitamin C loss of sample treated by ohmic (48.02% – 65.80%) was lower than that of water blanching (71.19%).	Icier, 2010
	Grape	Ohmically heated in solution containing 2% citric acid to 60 °C, used a field strength of 15 V/cm, and conducted at 30 Hz, 60 Hz, and 7.5 kHz, respectively.	Dried by food dehydrator	Significantly increased the drying rate, and related to the frequency of alternating current, being highest at low frequencies (30 and 60 Hz) and lowest at a high frequency (7.5 kHz).	Salengke & Sastry, 2005
	Apple	Blanched samples at 95 °C during 1 min, with electric field intensity of 60 V/m and frequency of 50 Hz.	Osmotic dehydration	The dehydration time to obtain a weight loss of about 25% was reduced by 75%.	Allali et al., 2009
	Strawberry	Blanching temperature was 60 to 85 ± 2 °C and heating time from 0 to 3 min.	Osmotic dehydration	Increased the mass transfer and the effective diffusion rates.	Allali et al., 2010
Microwave blanching (MVB)	Purple flesh sweet potato	Performed in a domestic oven, input power: 1,200 W, output 700 W.	Microwave- -spouted bed drying	Resulted in rapidly inactivated POD, reduced the drying time, maintained the anthocyanin level of dried products.	Liu et al., 2015
	Green beans	Microwaved for 125 s at 900 W, 150 s at 750 W, and 170 s at 650 W.	Without drying	Processing times were reduced by about half, and the retention of ascorbic acid increased by 50%–64%, as compared to samples blanched by hot water.	Ruiz-Ojeda & Peñas, 2013
	Carrot	Microwave power (360–900 W), blanching time (10–300 s) and blanching water volume (0–150 mL).	Without drying	MWB times of the 630 and 900 W were lower than conventional blanching (CB), and more effective than CB in inactivating pectin methylesterase; when conducted at MVB with 360 W for 300 s, obtained higher quality products.	Sezer & Demirdöven, 2015
	Agaricus bisporus	Heated in a 2450-MHz microwave oven with power of 800 W, samples were heated until the center temperature maintained at 100 °C for 1 min.	Microwave–vacuum drying (MVD)	Improved the MVD process, obtained more uniform microstructure than hot water blanching.	Jiang et al., 2015

(*Continued on next page*)

Table 2. (*Continued*)

Methods	Product	Pretreatment process	Drying method	Main conclusion	Reference
	Sweet potato	Input power: 1200 W, output 700 W, at maximum power.	Microwave assisted spouted bed drying (MWSB)	Microwave blanching improved the MWSB drying process, reduced the drying time, and maintained the anthocyanin level in dried products.	Liu et al., 2015
	Strawberry	400 g of fruit were exposed to 400 W for 2.5 min and afterwards cooled in water at 15°C.	Osmotic dehydration	Reduced firmness and color changes, well preserved cells of sample.	Moreno et al., 2000
	Centella asiatica (L.) Urban leaves	Leaves were blanched in a microwave oven at 800 W and frequency of 2450 MHz for 15, 30, 45 and 60 s.	Heat pump-assisted dehumidified drying	Increased moisture diffusivities and rehydration ratio, when blanched for 30 s retained the highest total phenolics.	Trirattanapikul & Phoungchandang, 2014

uniformity, and optimize of the SSIB process, to extend its applications in the food industry (Xiao et al., 2014).

3.1.4 Ohmic heat blanching

Ohmic heating (OH) blanching is a thermal process in which heat is internally generated by the passage of alternating electrical current through a body such as a food system that serves as an electrical resistance (Shirsat et al., 2004; Jakób et al., 2010). During ohmic heating, food products are placed between two electrodes, and product temperature rapidly increases. OH has immense potential for achieving rapid and relatively uniform heating, reducing the treatment time that is critical to avoid excessive thermal damage to labile substances (Zareifard et al., 2003), providing microbiologically safety and high quality foods, and causing electroporation of the cell membranes by solubilizing the pectin substances which result in migration of moisture more easily (Kulshrestha & Sastry, 2006). What's more, OH has advantages of energy efficiency and an environment friendly process, compared to conventional water blanching (Varghese et al., 2014).

OH can be used as an alternative fast blanching method for fruits and vegetables (Icier et al., 2006), especially of whole large vegetables and fruits where the process may be accomplished in a relatively short time, usually few seconds, regardless of the shape and the size of the product (Mizrahi, 1996). It has been used to inactivate oxidase and intensify both heat and mass transfer (Kemp & Fryer, 2007; Zhong & Lima, 2003) in certain fruits and vegetables, as well as preserves nutritional and organoleptic quality of products (Salengke & Sastry, 2005; Allali et al., 2009 & 2010; Icier, 2010), as summarized in Table 2. Guida et al. (2013) observed that compared to hot water (100 °C) blanching, ohmic (24 V/cm, 80 °C) blanching inactivated both POD and PPO at 25% shorter processing times; the protein, polyphenolic and chlorogenic acid content of the product were well preserved, which were at range of 9–128%, 53–78% and 200–300% higher than water blanching samples, respectively. Vikram et al. (2005) found that, the reaction rate constants for vitamin C degradation of ohmic heated orange juice was 32%, 46% and 52% lowered than conventional, infrared and microwave heated samples at 50 °C, respectively.

Ohmic blanching efficiency is related to electrical frequency, field strength, voltage, particle size, ionic concentration, and electrodes (Kaur & Singh, 2016). Salengke & Sastry (2005) reported that, ohmic pretreatment at a low electrical frequency is more conducive to subsequent drying, raisins dried for 30 h, moisture contents of the samples were reduced from an initial average value of 81.2% wet basis to 23.9%, 23.8%, 38.3%, and 44.97% wet basis for the 30 Hz, 60 Hz, 7.5 kHz pretreatments, and no pretreatment, respectively. Allali et al. (2010) reported that, ohmic heating enhanced mass transfer during the osmotic dehydration of strawberry halves, water loss and sugar gain rose with an increase of temperature and duration of ohmic blanching. In addition, the blanching efficiency is dependent on the energy generation, which is proportional to the square of the local electric field strength and the electrical conductivity of the product (Goullieux & Pain, 2005). Therefore, metal ions or acidic solutions are often used to enhance the electric conductivity (Xiao et al., 2017).

However, there are limitations of ohmic blanching should be emphasized. For instance, the quality degradation may be accelerated by the electrolysis of water, which yields hydrogen at the cathode and oxygen at the anode (Sarkis et al., 2013); the added ionic substances, such as acids and salts, can accelerate corrosion of electrodes (Xiao et al., 2017); it is difficult to achieve dynamic and static performance of the temperature controlling, and heating uniformity for complex heterogeneous foods (Sakr & Liu, 2014).

3.1.5 Microwave heating

Microwaves (MW) are electromagnetic waves with frequency varies within 300 MHz to 300 GHz, and wavelengths range from 1 mm to 1 m (Mujumdar, 2006; Chandrasekaran et al., 2013). Microwave heating, as radiofrequency heating, is based on the use of electromagnetic waves of certain frequencies to generate heat in a material (Spigno, 2016), the electric energy conversion is evaluated to be approximately 50% and efficiency of MW heating can reach up to 65% (Nguyen et al., 2013). During microwave heating, the materials absorb microwave energy and convert it into heat by dielectric heating caused by molecular dipole rotation and agitation of charged ions within a high-frequency alternating electric field (Spigno, 2016), the heat generated volumetrically throughout a product rather than relying on the slow conduction of heat through its surface (Regier & Schubert, 2001; Rahath et al., 2016).

Compared to conventional heating, microwave blanching (MWB) has faster heating rates as microwave heating takes place within the wet biological materials, and it increases with the effective output power used (Ranjan et al., 2016; Ruiz-Ojeda & Peñas, 2013). MWB requires lower processing time, has higher heating efficiency and nutrient retention compared to conventional methods (Krokida et al., 2000), and reduces the drying time of agro-products, as summarized in Table 2. For instance, pectin methylesterase residual activities of carrot slices treated by water blanching and MWB for 300s were 0.099 and 0.0162 μmol/min/g, respectively; total pectin and total dry matter of MWB ones were 25%–50% and 40%–86% higher than water blanching samples, respectively (Sezer & Demirdöven, 2015). Liu et al. (2015) also observed that HWB, SB, and MWB treatments required 130, 110, and 60 s to reach 90% enzyme activity degradation in purple flesh sweet potato, respectively; MWB reduced the drying time and increased lightness (L value) of samples by 28.6% and 24.42%–36.66%, compared to SB and HWB, respectively; moreover, the anthocyanin retention of dried products treated by MWB (59.34%) were higher than HWB and SB samples (53.55% and 40.37%, respectively). Jiang et al. (2015) found MWB reduced the drying time of *Agaricus bisporus* slices by 22% compared with that blanched by hot water, the micro-structure of the MWB-treated sample was more uniform than that of the HWB sample.

However, there are some drawbacks of MWB that impedes its application. On the one hand, MW heating is very difficult to have a homogeneous treatment, which is some points remain at a lower temperature receiving an inadequate lethality while others overheat (Vadivambal & Jayas, 2010). On the other hand, the temperature is a not easily predictable or controllable manner, as the typical frequencies of MW heating, the origin of dielectric loss is due to ion conductivity and dipole orientation, these effects are frequency dependent (Regier & Schubert, 2001), and effected by sample type, shape, size, composition, moisture content, and etc. (Datta et al., 2005). Furthermore, the limited penetration depth of microwave also worsens the non-uniform heating of microwave heating (Koskiniemi et al., 2011).

3.2 Non-thermal process

Thermal pretreatments have been reported to be responsible for undesirable changes in quality attributes of fruits and vegetables, such as, tissue cell membrane disruption, protein denaturation, phytochemicals thermal degradation, poor firmness and crispness (Lee et al., 2006; Belie et al., 2000). Due to their important superiority in alleviating the quality degradation of agro-products, non-thermal process techniques have attracted increasing attention within the food industry (Rastogi, 2011).

3.2.1 Ultrasonic field

Ultrasound is a kind of mechanical waves with a frequency between 20 kHz and 1 MHz, and which requires an elastic medium to spread (Paniwnyk L., 2016). It is characterized by the formation, growth, and collapse of bubbles when sound waves are in contact with a liquid medium, this phenomenon is called cavitation and there is generation of thousands of bubbles and cavities (Bermúdez-Aguirre & Barbosa-Cánovas, 2016). Ultrasound has been demonstrated to improve mass transfer in food owns to exist direct (inertial flow and "sponge effect") and indirect effects (micro channel formation) (Miano et al., 2015; Tao & Sun, 2015), caused by mechanical fluctuation and cavitation effect of ultrasound (Beck et al., 2014; Fan et al., 2008; Gamboa-Santos et al., 2014). Furthermore, ultrasonic can be conducted at ambient temperature due to its low heating effect, the heat-sensitive compounds of food can be well protected (Chemat et al., 2011).

The research of ultrasound pretreatment on agro-products has received increasing interest (Rodrigues & Fernandes, 2007b; Schössler et al., 2012). Recently, ultrasound has been commonly used as a pretreatment processing to assist drying of agro-products, as illustrated in Table 3. Ultrasound has been proved to enhance the drying rate by altering micro-structure of plant tissue (Rodrigues & Fernandes, 2007b; Tao et al., 2016; Tao & Sun, 2015), and improve quality of products by shortening drying time and increasing the extraction ability of compounds (Çakmak et al., 2016). For instant, ultrasound treatment lead to breakdown of cells in carrots, and longer ultrasound treatment time resulted in greater structure destruction of carrot, as showed in Fig. 3 (Nowacka & Wedzik, 2016). The ultrasound pretreatment reduced the drying time by 31% in comparison to untreated apple cubes, the dried products treated by ultrasound exhibited 6%–20% lower density, and porosity of 9%–14% higher than untreated samples (Nowacka et al., 2012). Tao & Sun (2015) showed that, the drying kinetic increases with the increase of acoustic intensity within certain limits, the ultrasonic efficiency is closely related to acoustic intensity. What's more, ultrasound pretreatment conduced to a better color maintaining in dried carrots, and carotenoid contents in dried material treated with ultrasound at a frequency of 21 kHz for 10 and 20 min were 2% and 24% higher than untreated samples (Nowacka & Wedzik, 2016).

However, the structural damages of plant tissue simultaneously lead to decrease the phytochemicals content in products, as lacking of a barrier in the form of a compact layer of cells on the surface contributed, and then facilitating leakage of bioactive compounds from internal matrix to the external solution (Miano et al., 2015; Mieszczakowska-Frąc et al., 2016; Zhao et al., 2014). In the work performed by Mieszczakowska-Frąc et al. (2016), the ultrasound pretreatment modified the tissue structure of apple, which caused high loss of polyphenol (35%–54%), monomeric catechins (10%–34%), hydroxycinnamic acids (55%), and dihydrochalcons (63%). Siucińska et al. (2016) also observed that ultrasound pretreatment decreased the anthocyanin content of sour cherries by 11.6%, and antioxidant capacity deterioration rate during the first 8 weeks of storage was higher (42.7%), while the antioxidant capacity deterioration rate of non-sonicated sample was 35.9%. Similar phenomenon was observed by Stojanovic & Silva (2007) when they pretreated rabbiteye blueberries.

Ultrasonic pretreatment has advantages in reducing processing time and maintaining product quality to some extent. While, the ultrasonic technology is still in a stage of lab scale, due to the complexity to scale-up the equipment to industry size with the same working conditions and results. And the most urgent issue is the intensity of cavitation decreases as the medium is away from the tip of the sonotrode generating a non-homogeneous process and also because the small diameter of the sonotrode tip that has been designed to supply high amplitudes (Peshkovsky et al. 2013). In addition, ultrasound requires a coupling medium (such as gel, water or oil) to spread, which intensifies the loss of phytochemicals by leaking from plants tissues to the medium, and limits the application of ultrasonic in food industry in turn. Therefore, a novel non-contact ultrasonic technique, which takes air as the coupling medium should be developed (Álvarez-Arenas, 2010), and conquer practical difficulties to meet large-scale needs of industry as the radiating area of transducers is very small (Gallego-Juarez et al., 1999).

3.2.2 Freezing

Freezing pretreatment usually conducted at −20°C for several hours and then thawed to room temperature. During freezing, large ice crystals are formed and result in a breakdown of the cellular structure and setting of the porous structure (Sripinyowanich & Noomhorm, 2013), that facilitates water migration and enhance mass transfer. So, freezing has been utilized as pre-drying treatment of fruits and vegetables to accelerate the drying process, and maintain the product quality (Eshtiaghi et al, 1994; Ando et al., 2016; Albertos et al., 2016).

In the study by Ando et al. (2016), the frozen-thawed carrot roots had the higher drying rate than blanched and non-treated samples, and the cell membrane capacitance of frozen-thawed samples (1.71) significantly lowered than fresh (3.24) and blanched at 60–80°C (2.74–2.97). It indicated that physical destruction was caused by formation of ice crystals during freezing, as shown in Fig. 4. Kowalska et al. (2008) revealed that, freezing pretreatments before

Table 3. Effects of non-thermal physical pretreatments on drying characteristics and quality attributes of fruits and vegetables.

Methods	Product	Treatment process	Drying method	Main conclusion	Reference
Ultrasound	Parsley leaves	Carried out for 20 min in an ultrasound bath at frequency of 21 kHz.	Microwave-convective drying	Intensified drying process (reduction of drying time by 29.8% and energy expenditures by 33.6%) than blanching treated, increased the color stability, and reduced the bioactive components degradation.	Sledz et al., 2016
	Melon	Immersed in distilled water and submitted to ultrasonic waves during 10, 20, and 30 min.	Hot air drying	Increased water effective diffusivity of 39.3%, reduced the drying time of about 25%, caused a loss of reducing sugars up to 52% in sample after 30min of ultrasound.	Rodrigues & Fernandes, 2007b
	Mulberry leaves	3.0 g sample, immersed into 50 mL of distilled water, as the amplitudes used included 30, 50 and 70%, respectively.	Hot air drying	Reduced the total processing time by 17.2%, the quality properties of dried leaves pretreated by ultrasound were comparable to control samples.	Tao et al., 2016
	Banana	Immersed sample in distilled water and submitted to ultrasonic waves for 10, 20 and 30 min, at 30 °C, the ultrasound frequency was 25 kHz.	Fixed bed drying	When pretreated for 20 min, the drying time of samples was reduced to 207 min at 50 °C, while untreated sample took around 345 min.	Azoubel et al., 2010
		Pretreated with the ultrasonic bath for 10, 20 and 30 min, at 30 °C, the ultrasound frequency was 25 kHz and the intensity was 4870 W/m^2.	Hot air drying	When pretreated for 20 min, the D_{eff} was increased by 14.4%, drying time was reduced by 11%, caused a 12.1% loss of reducing sugars in products.	Fernandes & Rodrigues, 2007
	Pineapple	Pretreated with ultrasonic bath for 10, 20 and 30 min, ultrasound frequency was 25 kHz and the intensity was 4870 W/m^2.	Hot air drying	The drying time required to achieve a moisture content of 0.05 g water/g dry solids was reduced by 4%–23%.	Fernandes & Rodrigues, 2008
	Mushroom	The sonication pretreatments were carried out for 10, 20, and 30 min at 30 °C.	Hot air drying	Increased drying rate, significantly reduced the drying time by 11–33%, preserved the phenolic content and color values better.	Çakmak et al., 2016
	Mushroom, Brussel sprout and cauliflower	Pretreated with 20 kHz probe and 40 kHz bath for 3 and 10 min.	Freeze drying or conventional drying	Enhanced drying rate, reduced the drying time, and improved rehydration properties of samples, compared to blanched and untreated.	Jambrak et al., 2007
	Carrot	Conducted in a ultrasonic bath, provided 21 and 35 kHz frequency for 10, 20 and 30 min.	Convective drying	Decreased the D_{eff}, created micro-channels, provided better color and carotenoids content preservation in dried samples.	Nowacka & Wedzik, 2016
	Apple	Provided at a frequency of 35 kHz for 10, 20 and 30 min in the ultrasound bath at room temperature.	Convective drying	Caused reduction of the drying time by 31%, exhibited 9%–11% higher shrinkage, 6%–20% lower density, and porosity of 9%–14% higher than untreated sample.	Nowacka et al., 2012
		Placed in a water bath fitted with ultrasound transducers (25 kHz, 0.1 W/cm^3) at 40 °C for 45 and 90 min.	Without drying	Increased in polyphenol compound losses, lowered procyanidin polymerization, caused an apple tissue structure modification.	Mieszczakowska-Frąc et al., 2016
Freezing	Carrot	Frozen at 233 K for more than 10 h.	Fluidized-bed drying	Accelerated drying rate, reduced volume change for carrots.	Tatemoto et al., 2015
		Used a blast air freezer, maintained the frozen samples at -20 °C overnight.	vacuum frying	Helped in maintaining phenolic content and antioxidant capacity of the samples, increased crispness values, and reduced oil absorption.	Albertos et al., 2016
		Frozen at -20 °C in a thermostatic chamber for 12 h and thawed by soaking in distilled water at room temperature for 15 min.	Hot air drying	Drying rate was increased by 36%, capacitance of cell membrane and pectin methylesterase activities were reduced by more than 40% and 70%, respectively.	Ando et al., 2016
	Green beans, carrot and potato	Frozen in a freezing chamber at -18 °C for 24 h.	Fluidized bed drying	Freezing resulted in highest drying rates, gave good rehydration.	Eshtiaghi et al., 1994

(Continued on next page)

Table 3. (*Continued*)

Methods	Product	Treatment process	Drying method	Main conclusion	Reference
	Pumpkin	Frozen at −18 °C for 16 h.	Osmotic dehydration	Increase solids gain and water loss.	Kowalska, 2008
	Banana	Frozen at -34 °C for 1 h, then stored at -18 °C overnight and finally thawed at room temperature for 3 h.	Heat pump drying	Decreased the drying time by 46%, increased D_{eff} by 187%.	Dandamrongrak et al., 2002
Pulsed electric field (PEF)	Carrot	Electric field intensity of 0.60 kV/cm and duration of 50 ms.	Hot air drying	The PEF treatment increased the D_{eff}, reduced the air drying time.	Amami et al., 2008
	Apple	Constant field strengths were: 0.10, 0.20, 0.45, 0.65, 0.90, and 1.10 kV = cm, and a treatment duration of $t_{PEF} = 0.1$ s.	Osmotic dehydration	PEF pretreatment decreased sugar concentration in the osmotic solution and higher solid content in apple samples, improved mass transfer coefficients.	Amami et al., 2005
		Electric field intensity of 5–10 kV / cm, pulse numbers of 10–50.	Hot air drying	Increased the effective moisture coefficient by 20%, induced a reduction in drying time of up to 12%, when 10 kV/cm and 50 pulses were applied.	Wiktor et al., 2013
	Beetroot	Pulse duration 10 ms, pulse repetition time 200 ms, number of pulses 5500, inter-train pause 60 s, and number of trains 1000.	Convective air drying	Resulted in greater degree of tissue shrinkage and increased in rehydration time, with preservation of colorants.	Shynkaryk et al., 2008
	Potato	Pulses ranged from 5 to 120 and the pulse width was set at 100 μs	Convective air drying	The diffusion coefficients of pretreated samples increased by up to 40%.	Arevalo et al., 2004
	Red pepper	Electric field strength of 1.0 – 2.5 kV/cm, pulse width of 30 μs, pulse frequency of 100 Hz, for 1, 2, and 4 s.	Convective drying	Caused cell membrane disruption, reduces drying time by 34.7% reduction in, and maintained color quality (2.5 kV/cm, 100 Hz, 4 s).	Won et al., 2014
	Raphanus sativus	Pulse intensity of 1446 V/cm, pulse number of 87, duration for 28 μs.	Microwave-assisted spouted bed drying	Improved drying rate and vitamin C retained content.	Liu et al., 2015
High hydrostatic pressure (HHP)	Aloe vera	HHP (300, 400, and 500 MPa) treated for 5, 10, and 15 min at the ambient temperature (25° C).	Hot air drying	Enhanced drying rate, reduced drying time, improved rehydration ability, and modified the texture of the products	Hulle & Rao, 2015
	Aloe vera gel	HHP at 350 MPa for a period of 30 s.	Convective drying	Increased the water diffusion coefficient, modified the microstructure, increased firmness and retained high antioxidant activity.	Vega-Gálvez et al., 2011
	Carrot, apple, and green bean	Treated at different pressure–time –temperature combinations (100 – 300 MPa for 5 – 45 min at 20 and 35 °C).	Hot air drying	HHP treatments at above 100 MPa caused a significant decrease in the drying times of apples, carrots and green beans.	Yucel et al., 2010
	Potato	Immersed in 1% citric acid solution, and treated at 400 MPa for 15 min.	Hot air drying	Enhanced drying rate, maintain better color, higher apparent density and hardness of sample than thermal blanching.	Al-Khuseibi et al., 2005
	Red paprika	Treated at 400 MPa for 10 min at 25 °C.	Fluidized bed drying	Resulted in higher drying rates, as well as higher mass and heat transfer coefficients.	Ade-Omowaye et al., 2001b
	Banana	HHP of 200 MPa for 5 min at 26 °C	Dehumidified air drying	Reduced bulk, improved flavor, decreased a_w , and reduced dehydration time and energy.	Verma et al., 2014
	Strawberry	HHP at 200, 300 and 400 MPa, time intervals from 0–10 min.	Osmotic dehydration	Improved strawberries dehydration rates.	Nuñez-Mancilla et al., 2011

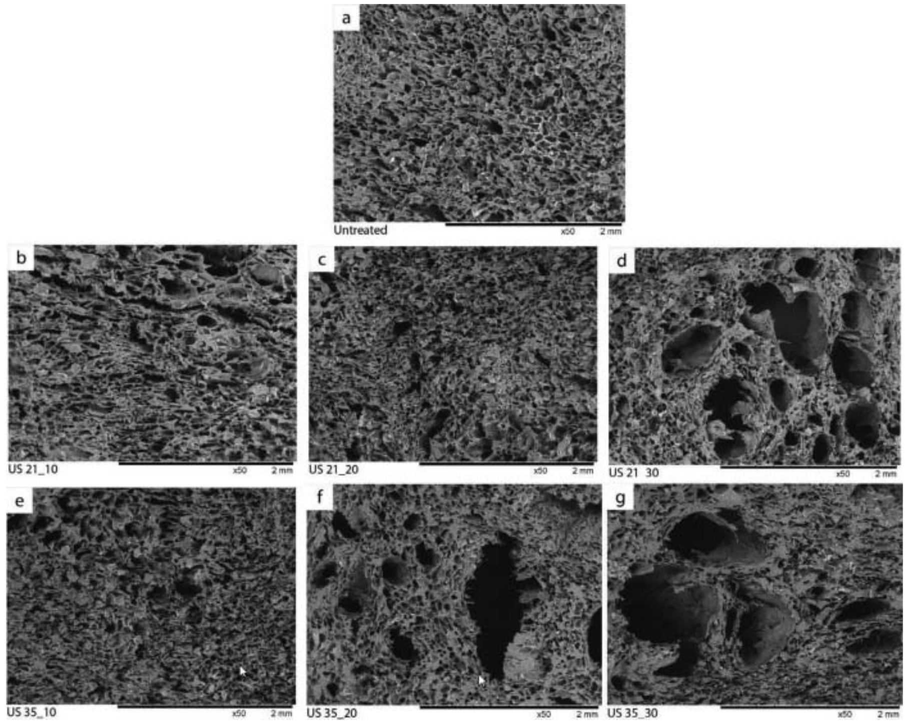

Figure 3. Cross section of carrot vascular tissue; untreated (a), ultrasound treated with frequency 21 kHz for 10 (b), 20 (c) and 30 (d) minutes, ultrasound treated with frequency 35 kHz for 10 (e), 20 (f) and 30 (g) minues. (Nowacka & Wedzik, 2016).

osmotic dehydration of pumpkin gave higher water loss and especially increased solids gain compared to the samples without pretreatment. Pimpaporn et al. (2007) observed that, freezing pretreatment improved the lightness, crispness and also reduced the toughness of dried potato chips. Besides, because of a faster heat transfer between frozen cells, and water can rapidly evaporate from ice crystal state under vacuum condition, so that, freezing has been usually applied prior to vacuum drying to achieve a higher rate of heat transfer (Shyu & Hwang, 2001).

Though freezing treatment reduced the drying time by 46% compared to untreated banana, while the frozen samples exhibited extensive browning, as color value was 58% lower than control, resulted in product quality degradation (Dandamrongrak et al., 2003). As for instant rice drying, freezing pretreatment maintained the same textural properties to those of freshly cooked rice, but it had adverse effects on the quality of products resulted in high bulk density and shrinkage (Rewthong et al., 2011).

In short, freezing pretreatment can enhance drying rate and preserve the quality of products. However, the application of freezing pretreatment is very limited partly due to it can't inactivate the enzymes responsible for browning reactions, and probably cause nutrition loss during thawing. In addition, it possess a high operation cost only suitable for some high-value foods.

3.2.3 Pulsed electric field

Pulsed electric field (PEF) is one of non-thermal technology, which involves the application of short-duration (from μs to ms) electric pulses of high-voltage fields usually in the range of 15–80 kV/cm to foods placed between two electrodes (Evrendilek, 2016; Yan et al., 2017). PEF is usually applied on liquid or semisolid foods to inactivate microorganisms and enzymes at ambient and mild temperature conditions, without significantly affecting the original color, flavor, texture, and nutritional value of the food (Barbosa-Cánovas et al., 1999; Ade-Omowaye et al., 2001a). In recent years, it has been proved that PEF induced membrane permeability of cells and tissue disintegration for

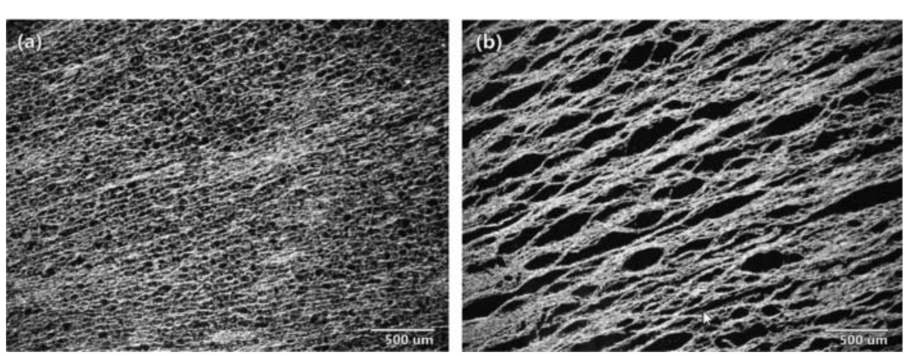

Figure 4. Microscopic images of phloem tissue of a fresh sample (a) and a frozen-thawed sample (b). (Ando et al., 2016).

improving mass transfer of plant materials (Knorr et al., 2011), which can be achieved at moderate electric fields of 200–1000 V/cm and short treatment time within 10^{-4}-10^{-2} s (Fincan & Dejmek, 2002; Lebovkaa et al., 2007).

PEF has been utilized to pretreatment of agro-products (Toepfl et al., 2005), and has significant positive effect on enhancing drying process of foods by improving the permeabiliation of cell membrances, and preserving food quality attributes by inactivating enzymes or shortening drying time (Amami et al., 2008; Amami et al., 2005; Dev & Raghavan, 2012; Wiktor et al., 2014), as shown in Table 3. PEF pretreatment increased the moisture diffusivity of red beetroot (Shynkaryk et al., 2008), improved the initial drying rate by 26% and reduced the drying time by more than 14% of raphanus sativus (Liu et al., 2016). Moreover, PEF slowed down the enzymatic action of ascorbic acid oxidase (AAO) in carrot purée, thus providing protection against vitamin C oxidation (Leong & Oey, 2014; Liu et al., 2016). It was also observed that the drying time of PEF pretreated red peppers was reduced by 34.7% and the color parameter b^* was increased by 10% compared to the un-pretreated samples (Won et al., 2014). In addition, it allowed a highly effective inactivation of microorganisms while retaining product quality, contributed to low processing temperature and short residence times (Toepfl et al., 2005).

An application of PEF for food drying pretreatment can increase the drying rate and reduce drying time of more than 20% depending on the products (Ade-Omowaye et al., 2001a). And it provides the tremendous potential to minimize undesirable changes in quality products at lower temperatures and short residence times to retain the fresh-like character and nutritional value of the products (Ranganathan et al., 2015). However, PEF is incapable of inactivating enzymes at conditions adequate for microbial inactivation (50–1000 kJ/kg) (Terefe et al., 2015; Jermann et al., 2015), it also causes cell damage and tissue softening (Faridnia et al., 2015), and the capital equipment costs were expensive (account for 54% of the total production cost) (Li & Farid., 2016), the foods have large particulates or relatively high electrical conductivity are not feasible (Ranganathan et al., 2015). Furthermore, material direct contact with electrode may cause electro-chemical reactions during PEF treatment, trigger corrode electrode and generate toxic substances in turn, and more works are needed to develop corrosion-resistant electrode.

3.2.4 High hydrostatic pressure

High hydrostatic pressure (HHP) is an innovative and emerging technology, which is a pressure-based technology. It involves applying a high-pressure shockwave (ranging from 100 to 800 MPa) transmitted through water to materials for a desired dwell time and temperature (Hulle & Rao, 2015; Ueno et al., 2009). When fruits and vegetables are pretreated with HHP, cell permeabilization induced by high-pressure may facilitate the diffusion and provide higher drying rates (Ueno et al., 2009; Al-Khuseibi et al., 2005; Yucel et al., 2010).

The applications of HHP technology prior to drying to decrease the drying time and minimize the deterioration of quality are increasing recently, as summarized in Table 3. Hulle & Rao (2015) showed that, HHP modified the texture of the aloe vera cubes, and by thus enhanced the moisture transfer rates, decreased in drying time by up to 32% (treated at 400MPa and above), and improved rehydration ability by about 32% (500MPa for 10min) compared to un-pretreated samples. Vega-Gálvez et al. (2011) also found that HHP pretreatment (350 MPa, 30s) increased the water diffusion coefficient by 22%, enhanced the antioxidant activity, modified the microstructure and texture of aloe vera gel. Assisted with osmotic dehydration, HHP has been demonstrated to improve the diffusion coefficients of water and soluble solids and thus in turn accelerated the water loss of samples (Nuñez-Mancilla et al., 2011; Verma et al., 2014; Rastogi et al., 2000). Tedjo et al. (2002) revealed that, the HHP treated mangos had a higher red intensity (a^* values) and solid gain than the untreated samples.

However, during high pressure processing, plant materials would suffer a great destruction of shape and structure. Hulle & Rao (2015) revealed that, HHP enhanced the firmness of aloe vera cubes with a maximum of up to 21% for the sample treated at 500 MPa for 15 min. Ueno et al. (2009) showed that, tissue softening induced by HHP treatment owned to destruction of cell membranes and partial liberation of cell substances. Besides, the application of HHP systems in industrial scale-up production is hindered by high equipment cost and low products throughput. The equipment cost of HHP systems is account for 59% of the total production cost, and prices of industrial scale HPP units vary from U$770,000 (55 L) to U$3,150,000 (420 L) according to a study by Li & Farid (2016). Moreover, more R&D is required to realize commercial application in food industry, such as the inactivation of enzymes by HHP is variable and uncertain, the serious destruction of structure and texture of solid plant materials, as well as pressurized mediums may permeate into foods (Jermann et al., 2015).

3.3 Other techniques

Besides, there are also other physical treatments applied on fruits and vegetables before drying, such as peel abrasion, skin puncturing and infrared heating. Matteo et al. (2000) indicated that, superficial abrasion of the grapes peel reduced the drying time by 61%, as compared to untreated grapes. Similarly, Adiletta et al. (2015) also found that the drying time of red grapes with abraded peel was reduced by about 67% and the dried product had higher rehydration capacity compared to untreated grapes. Yong et al. (2004) reported that pinholes and drilled holes improved the drying rate of potato, cassava, dragon fruit and red chilli, and it was increased by the diameter and density of the holes. Zhang et al. (2012) indicated that the drilling hole pretreatment significantly decreased the drying time (16%–31%), and reduce red pigment loss as well as browning of pepper. However, either peel abrasion or skin puncturing is impracticable in industrial scale because the operation processes of both pretreatments are tedious, laborious, and costly.

Infrared radiation energy with specific wavelengths can penetrate into product and directly heat water or desired components to achieve the purposes of blanching and the energy transfer is highly efficient (Nakamura, 1969; Rastogi, 2012). Shewale & Hebbar (2017) observed that infrared radiation pretreatment reduced the drying time of apple slices by nearly 23%, and improved the retention of ascorbic acid and total phenolic content with about 82%–90% and 72%–74%, respectively, when compared with the samples treated by potassium metabisulphite. Though infrared heating has advantages over conventional heating under similar conditions, such as short heating time, simple and compact equipment, significant energy saving, and inactivating enzymes (Bingol et al., 2014, 2012; Rastogi, 2012), there are drawbacks limit the application of infrared heating pretreatment, such as its poor penetrate deep in product with only a few millimeters below the surface of the sample, and causing serious water loss (up to 49%) of samples (Xiao et al., 2017).

4. Future trends

The novel thermal and non-thermal pretreatments may become the trends of developing of pre-drying treatment technology in the future. However, there are still many aspects need to be improved of these pretreatment techniques:

For novel thermal blanching, such as SSIB, MWB and OH, they are all still in the early stage of development, and usually used on small-scale for test. The most difficult problems hinder large-scale industrial application, are the non-uniform heating, and limited penetration depth of MWB. The temperature control system designs via mathematical modeling should be approached to improve the heating uniformity of blanching equipment, or even suit for complex heterogeneous foods. And with development of computer technology, material science, sensor technology, and online detection technology, there is scope for development of smart control system (Su et al., 2015). Equipped blanching facility with smart control system may realize the dynamic regulating of blanching conditions, minimize the energy consumption and quality deterioration.

For novel non-thermal technologies, such as ultrasonic, PEF and HHP, they have been conducted on small laboratory scales. A novel non-contact ultrasonic technique, corrosion-resistant electrode, and large-scale inexpensive equipment should be developed to meets the requirements of industrial production. Additionally, non-thermal pretreatments fail to efficiently inactivate the oxidases in plant materials, hence, combine with thermal pretreatment can achieve to the enzyme inactivation. Therefore, hybrid technology should be developed to better utilize of these techniques.

It is noted that, non-thermal pretreatments enhance drying process mainly by improving the permeabilization of cell membranes or destroying structure and texture of tissue. Microstructure is a key for revealing the properties changes during processing (Xiao and Gao, 2012). Many of the undesirable quality attributes changes such as brown discoloration, textural changes, off-flavors, nutritional loss are closely ralated with the microstructure changes during processing (Niamnuy et al., 2014). However, the relationships between microstructure changes and the evolution of macro physic-chemical properties of foods such as texture, color, rehydration ratio, reactions during pretreatment and drying have rarely been reported. Therefore, more investigation is needed to explore the relationships between pretreatments, microstructure, and physic-chemical properties of products so as to provide the opportunity to manage structure formation and tailor functional properties of food by selecting suitable pretreatment technologies and optimize the processing conditions.

5. Conclusions

In the production of dried food, the drying rate is crucial to reduce food quality deterioration and energy requirements. Pretreatment is an important operation commonly employed before drying to increase drying rate, maintain quality, and decrease microbial load of products. Diverse pretreatment techniques reviewed here, all of them have merits and demerits. Osmotic dehydration reduced the initial water content, drying time, as well as energy consumption, but detrimental to product quality, e.g., loss of minerals, vitamins, and pigments substances due to migration from tissue into osmotic solution. Chemical additives dipping techniques have advantages of enhancing drying process and maintaining quality of foods; while the residues in the food may cause food safety problems. Conventional blanching treatments effectively inactivate various enzymes, soften the texture and destroy microorganisms, accordingly enhance the quality and facilitate drying rate. However, it was described as unfavorable since causing undesirable changes of products, viz. loss of texture, soluble nutrients, pigment and aroma. Novel blanching treatments, such as high-humidity hot air impingement blanching, microwave and ohmic blanching could reduce the nutrition loss and are more efficient in comparison. Furthermore, novel non-thermal technologies can be a better alternative to thermal blanching to overcome the drawbacks of heat-sensitive compounds degradation. Nonetheless, the capital and running costs should be involved to evaluate the techno-economics. In order to bridge the gap between laboratory research and industrial applications of different pretreatments technologies, future research needs are discussed and identified.

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