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REVIEW PAPER

Effect of Pre-treatment on The Impregnation of Osmotically Dehydrated Fruits: A Review

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ABSTRACT

Osmotic dehydration is one of the alternative methods that is most frequently employed in the food industry to prevent large accumulation of food waste and postharvest losses, although it has a devastating influence on the textural and structural properties of the fruits. Considering that, this review offers innovative ideas and views on the impact of calcium salts, specifically calcium chloride and calcium lactate, on the impregnation of osmotically dehydrated fruits, along with various pre-treatments. Calcium chloride and calcium lactate salts assist in conserving the quality of fruits in the sense of colour, sensory, textural, structural, and other characteristics since some fruits are very perishable and rapidly degrade. Additional data showed that pre-treatments like blanching, freezing, drying, and ultrasound negatively affect calcium salt impregnation on fruit samples. The focus of this review is mainly on the preservation method of impregnating osmotically dehydrated fruits with calcium chloride and calcium lactate salt treatments, as well as blanching, freezing, drying, and ultrasound pre-treatments.

Keywords: Calcium chloride, calcium lactate, fruits, osmotic dehydration, pre-treatments, sucrose

INTRODUCTION

A huge array of fruit products is available on the market, including processed, fresh-cut, dried, canned, juice, chips, jam, and others because of their sweet, tangy, and crispy taste (Silva *et al*., 2014; Sarabo *et al*., 2021). Conversely, some fruits have relatively short storage and shelf life. Furthermore, these fruits cannot be stored for extended periods of time because the chemical components of fruits have begun to degrade, resulting in loss of quality in terms of nutrients, texture, colour, aroma, and flavour due to processing, ripening, senescence, and microbial growth (Fernandes *et al*., 2006; Silva *et al*., 2014). Adversely, consumers have high demand for good quality products that maintain the freshness of the fruits.

Therefore, numerous types of physical preservation methods such as freezing, dehydration, irradiation, and pasteurization, which are considered mild heat treatments, were used to prevent or minimise postharvest loss of fruits (Pereira *et al*., 2007; Yadav & Singh, 2014). However, these processes significantly alter the flavour, colour, and aroma of the food, as well as the sensory and nutritional value, which might make consumers lose interest in incorporating healthier options into their daily diets (Lenart, 1996; Pereira *et al*., 2007).

To support these physical preservation methods, osmotic dehydration is one of the alternative additional preservative methods that can be applied to sustain the final quality and shelf life of minimally processed fruits. Osmotic dehydration is the partial removal of water from fruits and vegetables using hypertonic solution without any thermal treatments, which is primarily employed in several traditional physical preservation methods. Fruit quality has improved, while energy costs have decreased (Kowalska *et al*., 2008; Silva *et al*., 2014).

Previous research found that combining calcium salts, specifically calcium chloride and calcium lactate treatments, with blanching, freezing, drying, and ultrasound methods prior to osmotic dehydration accelerated mass transfer, shortened processing time, increased cell permeabilization, and prevented browning in fruits (Tedjo *et al*., 2002; Ade-Omowaye *et al*., 2003; Silva *et al*., 2014). Pre-treated osmotically dehydrated fruits are commonly used in the baking, dairy, and confectionery industries because the fruits seem fresh after the osmotic dehydration process, which removes 20% to 30% of the water. In the same way, jam manufacturing companies manufacture good quality jams, notably kiwi and orange jam, from pre-treated osmotically dehydrated fruits rather than commercial ones since they provide the most desirable quality and longer shelf life for the end products (Akbarian *et al*., 2014).

Therefore, this review focuses on novel preservation methods of impregnating osmotically dehydrated fruits with calcium chloride and calcium lactate salt treatments, along with blanching, freezing, drying, and ultrasound method. The physicochemical properties, sensory analysis, and cellular permeabilisation of osmotically dehydrated fruits were studied through blanching, freezing, drying, and ultrasonic treatments. This alternative method has several synergetic effects, including preserving the texture and quality of fruits as well as increasing the fruit shelf life.

Quality of Fruits

In essence, all fruits are purchased or consumed based on their quality, which determines their market value and demand. The quality of fruits varies for each fruit type and species since they have different characteristics. The quality of fruits may be described as the combination of the characteristics that define specific units of fruit and are essential in influencing the degree of acceptance of that unit by consumers (Barrett *et al*., 2010). In addition, the quality of fruits is classified into three categories, including colour, flavour, and texture, which are always interrelated. Each attribute entices the consumers’ interest, prompting them to purchase fresh fruits as fresh-cut, minimally processed, and dried. The fruits are evaluated by the consumers using their senses, such as their eyes, nose, tongue, ear, and skin. Before the fruits can be further processed, they must meet a number of quality standards (Barrett *et al*., 2010).

To begin with, colour is an important quality in fruits since consumers eat and purchase them based on their colour. Several pigments contribute to the colour of fruits, and the pigments begin to change during the ripening and senescence stages. Ripening and senescence are a series of degradation processes that begin as fruits and vegetables mature. Most fruits and vegetables undergo metabolic disruption and cellular deterioration, which includes colour changes, ethylene production, and texture softening as a result of degradation (Alós *et al*., 2019). Chemical processes such as enzymatic browning and non-enzymatic browning, which produce brown pigment and are catalysed by enzymes such as polyphenol oxidase or peroxidase, can induce colour changes (Barrett *et al*., 2010). This reaction makes the fruit unfit for consumption. At the same time, buyers can discern whether the fruits are fit for human consumption based on the colour of the fruits. Meanwhile, colour is the first quality element that gives customers an idea of the flavour and texture. As a result, consumers believe and trust food product colour (Barrett *et al*., 2010; Deng *et al*., 2019).

Then, flavour is a fruit quality attribute that is developed by many volatile compounds and functional groups such as aldehydes, esters, and ketones that are available in the chemical components of fruits (Kader, 2008). The flavour is a mixture of aroma and taste; consumers can discover the taste of fruits through their smell, while they can determine the aroma of foods that have been released from fruits when they chew. Apart from the colour, the flavour of the fruits creates a huge impact on whether the consumers want to purchase them again or not (Barrett *et al*., 2010). So, the taste of fruits is classified into five flavours, including sweet, sour, salty, bitter, and umami. Each fruit has a distinct flavour, such as the orange's sour taste, the banana's sweet taste, and the grapefruit's somewhat bitter taste (Barrett *et al*., 2010). But the flavour has begun to vary based on several factors, such as the fruit’s genetics, storage condition, harvesting, handling, and maturity stages (Kader, 2008).

In addition, after considering the colour and flavour, the texture is one of the qualities that consumers will consider when purchasing fruits. The texture is evaluated through the skin using the sense of touch (Barrett *et al*., 2010). The texture of fruit usually differs from that of other solid foods because the fruit has high amount of water, which makes the flesh softer and smoother. But certain fruits, such as apples and pineapple, are crisp while cantaloupes are mushy (Barrett *et al*., 2010). Usually, the textural qualities are always related to the structural qualities of fruits, including the middle lamella, vacuole, cell wall, and cell membrane. The textural quality of fruits is easily evaluated through the instrumental method by using equipment such as a texture analyser (Barrett *et al*., 2010).

Therefore, the food and pharmaceutical industries are evolving by using certain fruits to produce various fruit-based nutraceuticals and functional foods since it has attracted the consumers' attention over the last few years (Mohd Ali *et al*., 2020). Unfortunately, some consumers still rely on fresh-cut fruits or minimally processed fruits because they believe that these kinds of fruit products have more nutritional value than other functional foods and nutraceuticals. On the other hand, fresh-cut fruits are known as nutritious fruits that can prevent many health problems and illnesses, such as cancer and intestinal inflammation.

Osmotic Dehydration

Osmotic dehydration is a process used throughout the food industry to minimise post-harvest losses. It is the partial removal of water from plant cells such as fruits and vegetables at very low temperatures using hypertonic solutions. As a result, the fruits and vegetables are immersed in a hypertonic solution containing osmotic solutes like sucrose, glucose, fructose, maltodextrin, sorbitol, and others at various concentrations and temperatures (Akbarian *et al*., 2014; Silva *et al*., 2014). As the pressure of the hypertonic solution is high, water is diffused out of fruits and vegetables into the osmotic solution, while the osmotic solution is diffused into the fruits or vegetables from the highest gradient to the lowest gradient through a semi-permeable membrane. Then, sugar, minerals, vitamins, and other solutes in food tissues leach out into the osmotic solution (El-Aouar *et al*., 2006; Phisut *et al*., 2013; Akbarian *et al*., 2014; Silva *et al*., 2014; Yadav & Singh, 2014). Figure 1 shows the process of osmotic dehydration in fruits and vegetables.

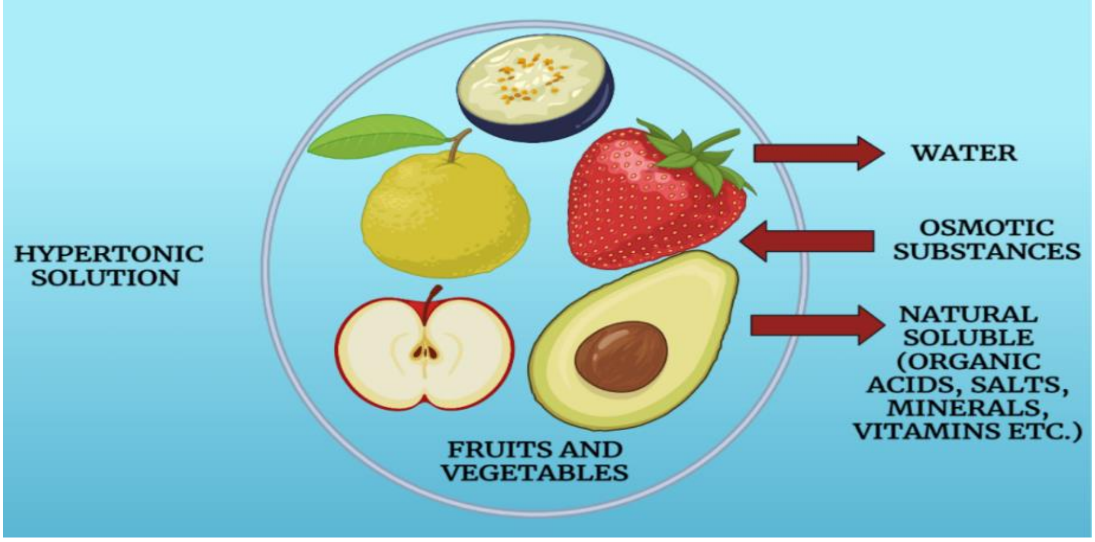

Figure 1. Osmotic dehydration in fruits and vegetables (Ramya & Jain, 2017)

In recent years, there has been an increase in demand for ready-to-eat foods. Alternatively, osmotic dehydration is a preservative method used by food industries on many different types of fruits and vegetables due to its beneficial effects, such as lowering thermal damage, significantly reducing flavour and colour loss by retarding enzymatic browning, inhibiting microbial growth, improving product stability, retaining nutrition, and limiting energy consumption (Moraga *et al*., 2009; Akbarian *et al*., 2014). However, the osmotic dehydration process is highly sensitive to a number of variables, including the type of osmotic agent used, the molecular weight of solutes, osmotic agent concentrations, processing temperatures, agitation or stirring procedures, and pre-treatment strategies (Akbarian *et al*., 2014; Yadav & Singh, 2014).

Moreover, osmotic dehydration has some cryoprotectant impacts on the appearance and texture of most fruits, where moisture content is reduced and sugar gain is observed during osmotic dehydration (Kowalska *et al*., 2008). Durrani and Verma (2011) investigated the shelf life of carrot candies subjected to osmotic dehydration, a method in which carrot candies were prepared using honey rather than white sugar. The researchers discovered that carrot candy has a longer shelf life of six months in two different packaging materials, namely glass and LDPE (Low Density Polyethylene) packaging materials. Castelló *et al*. (2010) also investigated the effects of osmotic dehydration and storage on the respiration rate and physical attributes of strawberries. The results showed that osmotic dehydration does have an overall impact on the respiration rate as well as some other properties, including mechanical and optical properties. At the same time, changes in density, shrinkage, porosity, and shape of strawberry occurred.

Osmotic Agents

Sucrose

The osmotic agents play the most crucial role in osmotic dehydration since there is a wide range of osmotic agents such as sucrose, glucose, sorbitol, glycerol, glucose syrup, corn syrup, and others that are available and used as osmotic dehydration solutes in the food industry. In addition, the osmotic agents will have their functionality and provide effects on the preservation of fruits and vegetables (Ispir & Togrul, 2009; Tortoe, 2010; Phisut *et al*., 2013). In general, the selection of osmotic agents is extremely important in the food industry and must take several factors into account, including the price of solutes, which must be economical, and the sensory compatibility of the final product, and others. On the other hand, most previous research indicated that salt and sugar could be effective osmotic solutes due to their effectiveness, convenience, and taste in osmotically dehydrated fruits and vegetables (Tortoe, 2010).

At this point, some osmotic solutes, such as simple molecules, are most commonly used since they have a good diffusion rate through semi-permeable cell membranes and prevent the enzymatic browning reaction on the end products of fruits and vegetables. Moreover, the simplest sugars of carbohydrates, like glucose and sucrose, have been shown to be high-quality technologies due to their higher diffusion rate, which can influence the absorption of more sugar molecules that contribute to identical sensory qualities in both natural and dried products (Sousa *et al*., 2003).

Sucrose is typically derived from the condensation of glucose and fructose, with sucrose consisting of an α-glucose and fructose linked by a glycosidic bond (Akbarian *et al*., 2014). Moreover, the molecular weight of osmotic solutes is really important due to their ability to penetrate the semipermeable membrane. The other components pass slightly through the membrane, but the diffusion of water and low-molecular-weight material from the tissue structure will be easy during osmotic dehydration that is accompanied by back diffusion of osmotically active material (Tortoe, 2010).

Hence, sucrose is one of the osmotic agents that have low molecular weight. The shape of sucrose, which can easily diffuse and penetrate into the cells and tissues of fruits and vegetables, can preserve the quality of fruits and vegetables by preventing several chemical reactions such as enzymatic browning and oxidation that can cause the degradation of fruits (Chavan & Amarowicz, 2012; Akbarian *et al*., 2014; Yadav & Singh, 2014; Revati Rajanya & Singh, 2021). Most researchers conducted their studies on osmotically dehydrated fruits by using sucrose as an osmotic agent.

Ispir and Togrul (2009) investigated the effects of four different osmotic agents on the mass transfer of osmotically dehydrated apricots, finding that sucrose resulted in the greatest amounts of water loss. The researchers also considered sucrose as one of the best osmotic agents during the osmotic dehydration of apricots since it causes a high loss of water along with a low increase in solids (Ispir & Togrul, 2009). The sucrose is also known as sugar, whereas the dry sugar is less appropriate for use as an osmotic agent during the osmotic process due to oxidative browning reactions on the fruits. Subsequently, sucrose is the most effective osmotic agent because it prevents the ingress of oxygen and reduces browning. The sweet taste prevents its use in vegetable processing (Chavan & Amarowicz, 2012; Yadav & Singh, 2014).

Calcium chloride

Calcium salts, particularly calcium chloride, are widely utilised, especially in the food industry, since they provide significant benefits in the preservation of several fruits, such as pineapple quality, potentially minimising overall postharvest losses. Calcium chloride salt is used to minimise water activity, enzymatic browning, water loss, and plasmolysis, as well as to keep the fruit's textural features (Udomkun *et al*., 2014). Conversely, calcium salts aid in retaining the nutritional value of fruits that would otherwise be lost during processing, as well as preventing calcium-related infections and diseases such as osteoporosis, hypertension, cancer, and others in the human body. As a result, the food industry began to shift consumer attitudes toward consuming calcium-treated fruits rather than supplements that contribute to adequate calcium absorption in the human body (Cerklewski, 2005; Martin-Diana *et al*., 2007).

Calcium ions are relatively small and can diffuse passively within the cell structure because of the low porosity of the plant cell wall. When the parenchyma of fruit cells is immersed in a calcium chloride solution, calcium ions are predominantly transferred through the extracellular matrix, or intercellular spaces, where they are attracted by negatively charged carboxyl groups in the homogalacturonan that represents pectin in the middle lamella and cell wall (Ngamchuachit *et al*., 2014). On the other hand, there is unbound, negatively charged chloride in the solution. Calcium ions easily pass through the plasma membrane that surrounds each plant cell and the tonoplast, which is the membrane that covers the large water-filled vacuole prior to osmotic dehydration (Techakanon & Barrett, 2017).

In most cases, calcium chloride prevents the two cell structure occurrences, including plasmolysis and middle lamella detachment (Mayor *et al*., 2008). Calcium treatments enhance product texture and demonstrate a protective effect on tissue structure on a variety of processed fruits and vegetables, as shown in Table 1. Specifically, calcium chloride treatments have been shown to strengthen the fruit's texture and preserve tissue structure in a variety of minimally processed fruits (Luna-Guzman & Barrett, 2000; Quiles *et al*., 2004). Previous research has shown that the middle lamella and cellular walls of apples treated with calcium chloride do not change shape during storage and retain their cell-to-cell contacts (Glenn & Poovaiah, 1990). Therefore, the food industry most commonly uses calcium chloride to maintain the quality of fruits (Luna-Guzman & Barrett, 2000; Yang & Lawless, 2005).

Calcium lactate

Calcium lactate is one of the calcium salts that have become increasingly popular in the food industry in recent years, as calcium chloride imparts a bitter taste to the end product, perhaps reducing the consumer's interest. Calcium lactate is sometimes used as an alternative to calcium chloride since calcium lactate has been reported to have some distinct advantages over calcium chloride in that it avoids the bitter taste and undesirable flavour associated with the chloride salt that illustrated in Table 1 (Luna-Guzman & Barrett, 2000).

Table 1. Summary of the previous studies on different calcium salts and their effects on the quality of fruits and vegetables

Types of Calcium	Fruits/ Vegetables	Changes	Sources
Calcium chloride	Fresh cut guava, papaya, and muskmelon	• There are chemical changes where, after 20 days of storage, fresh-cut guava, papaya, and muskmelon treated with calcium chloride lost much more weight than untreated fruits. • There is a physical change where calcium chloride-treated fresh-cut guava, papaya, and muskmelon have a greater firmness value than the untreated fruits. • Calcium chloride-treated fresh cut guava, papaya, and muskmelon led to the decrease in *L*a*b** values.	Thakur *et al.* (2019)
	Ber fruits (*Ziziphus mauritiana Lamk.*)	• Ber fruits treated with calcium chloride underwent some chemical changes where the fruits have more pectin than untreated fruits, which helps to maintain cellular integrity by lowering uronic acid solubilization in pectin.	Jain *et al.* (2019)
	Strawberry	• The cellular integrity and cell wall components in the calcium chloride treated strawberry are significantly maintained, whereas the fresh, untreated strawberry has poor texture.	Langer *et al.* (2019)
Calcium lactate	Bitter gourd	• A study on the impact of calcium lactate on the postharvest quality of bitter gourd during cold storage discovered that calcium lactate contributes to both physical and chemical alterations in the bitter gourd.	Prajapati *et al.* (2021)
	Fresh-cut pineapple	• The effects of calcium ascorbate and calcium lactate on the quality of fresh-cut pineapple cause physicochemical and microbiological changes.	Troyo & Acedo (2019)

According to numerous research studies, calcium lactate has been employed as a firming agent for a variety of fruits, including cantaloupe, grapefruit, guava, and melon, as illustrated in Table 1 (Luna-Guzman & Barrett, 2000; Pereira *et al*., 2007; Moraga *et al*., 2009; Ferrari *et al*., 2010). Calcium lactate has properties, characteristics, and functions that are comparable to calcium chloride, and it is beneficial in protecting the quality of fresh-cut or minimally processed fruits by preventing the two phenomena that occur in osmotically dehydrated fruits.

The rate of respiration is shown to be lower in samples that are treated with calcium lactate. This impact could be due to an increase in membrane rigidity that prevents gas exchange, which may cause a delay in the arrival of spoilage and degradation or a reduction in active water transport (Kinoshita *et al*., 1995; Serrano *et al*., 2004). As seen above, both calcium chloride and calcium lactate-treated fruits have no substantial changes; rather, they prevent the bitter taste that influences the sensory qualities of osmotically dehydrated fruit (Pereira *et al*., 2007).

Types of Pre-treatments

Pre-treatments that have been applied to fruits prior to the osmotic dehydration play a significant role in preserving the fruits and extending their shelf life since the fruits are highly perishable and easily deteriorate. Chemical and physical pre-treatments are the two most common types of pre-treatments used on fruits. Both pre-treatments will modify and enhance the quality of fruits and vegetables since they minimise further processing time while also expediting the process by decreasing water activity and water content in the final goods. Meanwhile, chemical pre-treatments entail the use of chemicals such as acids, alkali, sulphur dioxide, ozone, carbon dioxide, sulphite liquor, and others that are safe for human consumption in accordance with the Malaysia Food Act 1983 and Malaysia Food

Regulation 1985. Physical pre-treatments, such as blanching, freezing, ultrasonic, and drying, are examples of low- or non-thermal processes that use relatively little or no heat, as illustrated in Table 2 (Deng *et al*., 2019). Both chemical and physical pre-treatments have advantages and disadvantages.

Table 2. Summary of the previous studies on different pre-treatments and their effects on the quality of fruits and vegetables

Type of Pre-treatments	Fruits/ Vegetables	Changes	Sources
Blanching	Carrot	Blanching pre-treatment contributes to physical changes. This blanching pre-treatment enhances the dehydration characteristics of the carrot in terms of texture.	Inyang & Ike (1998)
Freezing	Pomegranate seeds	The effects of freezing pre-treatment on osmotically dehydrated pomegranate seeds cause alterations, particularly physical changes due to the formation of ice crystals.	Bchir *et al.* (2012)
Drying	Pomegranate arils	The drying pre-treatment altered the physical changes on the pomegranate arils due to the longer drying period along with higher drying temperature.	Khoualdia *et al.* (2020)
Ultrasound	Apple	The ultrasound pre-treatment contributed to the both physical and chemical changes where ultrasound pre-treatment significantly altered the textural qualities and cellular structure of the apple.	Mieszczakowska-Frac *et al.* (2016)

Blanching

There are assorted pre-treatments available in the food industry prior to osmotic dehydration because osmotic dehydration has several adverse effects on the textural quality of fruits, particularly pineapple (Taiwo & Adeyemi, 2009). Each pre-treatment has its own set of properties and functions that help to preserve the fruit's quality and reduce post-harvest losses. Furthermore, blanching is most generally used in the food industry, particularly in the fruit-based manufacturing industry, because it can help to prevent excessive softening and enzymatic browning reactions, which are considered undesirable by consumers (Kowalska *et al*., 2008; Silva *et al*., 2014). The blanching may also extend the shelf life of minimally processed fruits by limiting microbial contamination and growth since some microorganisms can survive in extremely highly concentrated solutions (Garcia *et al*., 2021).

Enzymatic browning typically happens on fruits, particularly pineapple, where the reaction is known as an oxidative chemical reaction that occurs when the fruits are exposed to air or oxygen. However, blanching usually prevents this reaction because it causes the denaturation of enzymes such as polyphenol oxidase (PPO) and ascorbic acid oxidase, which are responsible for browning and contribute to the brown pigment on the surface of fruits. The PPO affects the appearance and organoleptic characteristics of fruits (Holzwarth *et al*., 2013; Ruiz-Ojeda & Penas, 2013; Vishwanathan *et al*., 2013).

Additionally, the blanching pre-treatment inhibits colour loss by maintaining the texture properties of fruits, especially pineapple, prior to the osmotic dehydration process (Inyang & Ike, 1998). Meanwhile, pre-treatments such as blanching have enhanced mass and heat transfer as well as product characteristics such as colour, texture, vitamin retention, and others of various fruits (Taiwo & Adeyemi, 2009). Blanching is a common unit operation used during the dehydration of most fruits and green vegetables. Previous research has indicated that the blanching of carrots improves the dehydration qualities of the vegetable. It also serves to maintain stable texture-structural quality attributes during dehydration and storage (Inyang & Ike, 1998).

Freezing

Agricultural commodities, particularly fruits, may need and preserve energy for future processing. Pre-treatment, such as freezing, facilitates subsequent processes such as drying and osmotic dehydration, as well as increasing the mass transfer rate of fruits (Deng *et al*., 2019). Many researchers reported that non-thermal pre-treatments, such as freezing, are excellent substitutes for thermal pre-treatments because thermal pre-treatment has significant negative effects on fruit quality, such as changes in texture and microstructure. Most food manufacturing companies have begun to use freezing as a pre-treatment prior to drying, osmotic dehydration, and other ways of creating high-quality minimally processed fruit. These non-thermal pre-treatments give various benefits to the food sector (Deng *et al*., 2019).

Freezing is one of the pre-treatments that is often performed under controlled settings for many hours at very low temperatures ranging from -18 °C to -20 °C, where the water particles in the fruits continue to freeze, creating huge ice crystals in the food matrix. These ice crystals affected the cellular structure, causing the cellular structure to collapse and the creation of porous structures, which hastened the water transition and elevated the mass transfer rate (Sripinyowanich & Noomhorm, 2013). Freezing is used to initiate further processing while preserving fruit quality and extending shelf life (Kowalska *et al*., 2008; Albertos *et al*., 2016; Ando *et al*., 2016).

According to Falade and Adelakun (2007), freezing pre-treatment is a preservation treatment that maintains African star apple pulp by enabling mass transfer prior to osmotic dehydration. When frozen and thawed African star apples were immersed in the osmotic solution for 30 minutes, they showed a considerable increase in water loss as well as solid gain when compared to fresh apples, which reported greater water loss after 2–3 hours of soaking. Bchir *et al*. (2012) investigated the effects of freezing pre-treatment on the osmotically dehydrated pomegranate seeds. The researchers found that pomegranate seeds were frozen before osmotic dehydration, which enhanced effective diffusion and thus lowered the dehydration time. During the first twenty minutes, the most significant variation in water loss and solids increase in frozen seeds was observed. Therefore, the fraction of solid gain on the pomegranate seeds rises when freezing is applied prior to osmotic dehydration.

There have been fewer studies on the effects of freezing pre-treatments on osmotically dehydrated fruit and vegetables, but several researchers have researched various types of fruits. Kowalska *et al*. (2008) investigated the effects of blanching and freezing on osmotically dehydrated pumpkins. The researchers studied the effects of both pre-treatments on the osmotically dehydrated pumpkin by immersing the chopped pumpkins in different osmotic solutions for three hours. But neither pre-treatment has a substantial effect on the water diffusion coefficient in the pumpkin.

Drying

Drying is one of the oldest methods or processes that is most extensively employed in the food industry since it has a wide application to food, particularly fruits and vegetables, where the food industry turns the majority of food into dried form. Drying can be done in a variety of ways, including solar drying, oven drying, sun drying, vacuum drying, freeze drying, microwave drying, batch drying, and continuous drying, depending on the demands of the food manufacturer and the client (Phuoc Minh *et al*., 2019).

Meanwhile, drying is regarded as one of the easiest techniques for removing moisture and reducing microbiological growth from food products by using both mass and heat transfer with evaporation at a specified time and temperature in order to produce desirable final goods (Phuoc Minh *et al*., 2019). However, drying has a significant adverse influence on the texture and microstructure of food, particularly fruits, where the cells in the fruits begin to rupture, causing the final dried fruits to shrink and become smaller in size owing to excess water loss during the drying process (Lewicki & Pawlak, 2003).

Furthermore, each kind of drying prior to osmotic dehydration has an influence on the final food products since the operation, time, air circulation, temperature, and length vary. Sun drying and solar drying take longer time to dry producing lower quality dried food items (Suresh & Sagar, 2010). Moreover, drying also influences the nutritional values of most fruits and vegetables since most nutrients, especially vitamins and minerals, are very susceptible to heat and are easily destroyed during the pre-treatments and can cause oxidation in fruits and vegetables (Suresh & Sagar, 2010). In contrast, the volatile chemicals present in the fruits begin to vaporise during drying, which can cause considerable aroma loss in the most aromatic fruits (Suresh & Sagar, 2010). In other words, aroma is always linked to flavour, as the flavour of fruits begins to deteriorate as the volatile chemicals degrade. As a result, the drying method aids in the reduction of microbial development, but the quality of fruits and vegetables started to decline due to the loss of aroma and flavour (Guine *et al*., 2017).

Ultrasound

In the same trend, ultrasound is another pre-treatment or preservation method that is regarded as the most revolutionary technology in the food industry since it is one of the non-thermal pre-treatments that might not require heat to treat the fruits and vegetables prior to osmotic dehydration. On the other hand, ultrasound pre-treatment offers a wide range of benefits to food manufacturing companies on a big and small scale due to mechanical, chemical, and biological changes in liquids and gases triggered by strong cavitation and the development of high-intensity acoustic fields (Gallo *et al*., 2018).

Ultrasound involves a sound wave in the form of energy with a varying frequency, with the strength of the frequency divided into two levels, including low and high waves. The frequency of the sound wave is approximately 18 kHz – 100 MHz, which the human ear cannot perceive (Gallo *et al*., 2018). Mason *et al*. (2010) and Kentish and Ashokkumar (2011) conducted studies on several fruits and vegetables and discovered the effects of ultrasound pre-treatment on the thermal, mechanical, and physicochemical properties. The researchers stated that higher frequencies of ultrasound result in improved energy absorption in fruits, where higher frequencies of ultrasound promote mass and energy transfer processes, resulting in enhanced food quality. The studies concluded that the temperature of the solution or gas, whether increasing or decreasing is determined by the frequency and strength of the ultrasound as well as the type of treatment applied.

Additionally, Mieszczakowska-Frac *et al*. (2016) conducted research on the effects of ultrasound on polyphenol retention in apples after drying, where the researchers discovered that the ultrasound pre-treatment altered the apple’s tissue structure, which may contribute to high loss of polyphenol, monomeric catechins, hydroxycinnamic, and others in varying percentages since the polyphenols are susceptible to high amounts of heat in the form of energy. However, even if ultrasound has certain detrimental effects on some food items, it is always helpful in extracting bioactive compounds from fruits and vegetables, assisting in the drying process of high-moisture foods, and mixing processes (Gallo *et al*., 2018).

Analysis Study

The following subtopics, consisting of functional groups, water holding capacity (WHC), colour, sensorial, textural, and morphological, are elaborated for determining the changes occur in the treated osmotically dehydrated fruits and vegetable samples. All subtopics are interconnected. These analyses illustrated that a combination of pre-treatments can effectively lessen the osmotic dehydration effect on fruits and vegetable samples while retaining the specified fruit quality for consumption. In summary, this subtopic explores the impacts of pre-treatments such as calcium salt treatments, as well as blanching, freezing, drying, ultrasound, and other methods, on the physicochemical aspects, sensory analysis, and cell and tissue permeability of the micro-structural of osmotically dehydrated fruit samples.

Functional group analysis

Functional group analysis is a qualitative technique for assessing the impact of osmotic dehydration by probing the functional groups present in treated fruit and comparing the results to those obtained from untreated fruit. Abdul Aziz *et al*. (2018) studied the frequency shifts, changes in band intensity, and shape or peak of the Fourier-transform infrared spectroscopy spectrum for the treated pineapple sample. The functional group analysis identified that there is a diverse variety of volatile chemicals and functional groups accessible in pineapple samples, which are altered by subsequent processing and treatments since each treatment will have a unique influence on the pineapple fruits by shifting the spectrum peak (Abdul Aziz *et al*., 2018).

Pineapple Morris, where the majority of pineapple samples have analogous functional groups, volatiles, phenolic compounds, and flavonoids (Lobo & Yahia, 2016). It contains the most known functional group, especially the ester group, which is responsible for the strong odour and aroma (Lasekan & Hussein, 2018). Furthermore, the results of ester compounds can also be determined by other instruments, such as headspace solid-phase microextraction and gas chromatography-mass spectrometry equipment in pineapple fruits (Wei *et al*., 2011).

Water holding capacity (WHC) analysis

WHC is defined as the capacity of fruits to retain how much water is inside the food matrix and is always associated with the structure of polysaccharides, generally known as fibre (Kethireddipalli *et al*., 2002). The ability of fibres to retain water *via* adsorption and absorption processes is an important physiological and commercial attribute. Outside the fibre matrix, some free water is also maintained (Sanchez-Zapata *et al*., 2011). Furthermore, fibre derived from plants has unique characteristics such as water and oil holding capacity, which may be employed in food items that require hydration to boost yield and adjust texture, as well as rheological properties in terms of viscosity (Selani *et al*., 2016).

Indeed, Borchani *et al*. (2012) evaluated the impact of various drying temperatures on the hydration characteristics of dates; the findings showed that increasing the drying temperature reduces WHC because different temperatures affect the structure of the fibre. Nevertheless, Monsoor (2005) discovered that several drying procedures (freeze drying, spray drying, and vacuum drying) had a negligible effect on soy hull WHC.

Selani *et al*. (2016) conducted a study on the physicochemical, functional, and antioxidant properties of tropical fruit co-products. It is observed that there is a significant difference in the WHC of the co-products derived from three different fruits (mango, pineapple, and passion fruit). The pineapple fruit has higher WHC values than the passion fruit and mango because the pineapple co-products are rich in fibre content and have the potential to be used in applications that need hydration. Additionally, the WHC is also related to pectin content, whereas a high content of pectin may enhance the WHC (Rubio-Senent *et al*., 2015). For example, Muhammad *et al*. (2020) proved that the dragon fruit peel pectin has somewhat lower WHC because it contains less pectin content.

Colour analysis

Colour is important in osmotically dehydrated fruits and vegetable samples because osmotic agents such as sucrose can maintain the colour from changing during further processing (Osorio *et al*., 2007). Those same changes are frequently observed in fruits and vegetables, where they are induced by pigment loss in fruit. The presence of browning during processing, or an enhancement in pigment composition due to water loss, which can also significantly raise the food's refractive index, can influences colour attributes of the fruits (Talens *et al*., 2002).

Falade *et al*. (2007) stated that colour influences product acceptability. In fact, the non-enzymatic browning reactions, including caramelisation and Maillard reactions, as well as a loss of lycopene pigment, cause the colour loss in most fruits and vegetables during the drying process. Moreover, the colour studies on the fresh-cut mango from Ngamchuachit *et al*. (2014) proved that calcium chloride and calcium lactate affected the textural and sensory aspects. The findings showed the mangos treated with calcium chloride has lighter orange flesh because the calcium ions suppress PPO enzyme activity in the mango fruits.

Another finding from Inyang and Ike (1998) showed that the blanching pre-treatment prior to dehydration facilitated the preservation of the colour pigment in the okra. It indicated that freshly dehydrated okra may have less colour absorbance than blanched okra, even though both the freshly dehydrated okra and the blanched okra samples lack of chlorophyll pigments. Regarding freezing pre-treatment, Falade and Adelakun (2007) studied the chroma value of African apples along with *L*a*b** values. According to the findings, frozen apple samples submerged in 52° Brix glucose solution had a higher chroma score than unfrozen apple samples submerged in various concentrations of osmotic dehydration solution. While the *L** values for both frozen and unfrozen apple samples were raised, the *a** and *b** values for both frozen and unfrozen apple samples dropped considerably throughout the storage period.

The effects of pre-drying osmotic dehydration on drying kinetics and end-product quality were investigated by Kowalski and Mierzwa (2011), who looked at how carrot colour changed over the drying process. The results proved that the colour of osmotically dehydrated carrots in 20% sucrose solution is nearly identical to that of fresh samples. Nonetheless, the colour of the osmotically dehydrated carrot in 60% sucrose solution differed from those of the fresh carrot sample. The variation in the visual appearance of an osmotically dehydrated fruit sample is thought to be influenced by the concentration of sucrose solution.

Nonetheless, Chu *et al*. (2021) conducted a study on the ultrasound and curing agent during osmotic dehydration to improve the quality properties of freeze-dried yellow peach slices, revealed that the ultrasound aids in pigment loss reduction by improving the collapse of cell structure integrity of osmotically dehydrated yellow peach slices. However, the *L*a*b** values of osmotically dehydrated yellow peach slices differ because the ultrasound pre-treatment suppressed the activity of the browning enzyme in order to preserve the colour of the osmotically dehydrated yellow peach slices. Meanwhile, when osmotically dehydrated yellow peach slices are subjected to higher ultrasound power, their *L** values increase but their *a** and *b** values decrease, possibly due to changes in interior tissue structures that lead to pigment loss.

Sensorial analysis

Sensory is a critical element that must be evaluated while producing and processing food products, particularly fruits, since each fruit has a distinct flavour and aroma that make it unique. Similarly, before releasing their food products to the public, each food manufacturing company conducted sensory evaluations with well-trained sensory panellists on a regular basis. For example, pineapple samples that were chemically pre-treated with calcium salts (calcium chloride and calcium lactate) over a specific storage period significantly influenced the organoleptic characteristics in terms of taste, flavour, colour, and texture (Inam-ur-Raheem *et al*., 2013).

Udomkun *et al*. (2014) investigated the influence of calcium salts such as calcium chloride and calcium lactate as pre-treatments on the sensory attributes of dried papaya. The findings revealed that aroma had the lowest scores where it was contributed by the drying process. Furthermore, the calcium content does not have any adverse impacts on the various attributes in terms of sweetness, acidic flavour, and aroma. However, the researchers found that there are significant variances in colour, texture, bitterness, and overall acceptability. The papaya samples treated with both calcium salts at varied doses had greater scores than the untreated papaya samples. The results of papaya samples that were treated with calcium chloride are identical to those treated with calcium lactate (Udomkun *et al*., 2014).

Furthermore, Pereira *et al*. (2007) reported that there were no significant variations in the major sensory attributes of the guava samples treated with calcium lactate on day 1 of shelf life. However, after 13 days of storage, the sensory acceptability of guava samples treated with calcium lactate declined, while the average scores for almost all sensory qualities examined fell below the acceptable range, resulting in sample rejection.

According to Zhao *et al*. (2014), the sensory analysis of frozen mango samples indicated that all osmo-dehydro frozen mangoes had improved quality attributes for overall acceptance when compared to conventional frozen samples. The osmotic dehydration prior to freezing massively reduces the freezing time by lowering the moisture content of the mango samples. Meanwhile, the researchers stated that the low water content of the osmotic-dehydrated food lessens freezing time as there is less water to freeze and hence less heat to dissipate. Furthermore, quicker freezing rate is assumed to be less harmful to tissue and more desirable for sample quality, resulting in greater scores for all sensory characteristics when compared to a conventionally frozen sample.

Adversely, the impacts found from blanching pre-treatments were reported by Stone *et al*.

(1986), who reported that unblanched okra received the lowest score, while blanched okra received the highest scores in terms of flavour and aroma. Blanching is strongly advised as one of the pre-treatments to inhibit the production of undesirable off-flavours and odours on the okra samples since the impregnation of 0.1 % SO_2 in the blanching water could not contribute any adverse effects on taste such as bitterness, sourness, or aftertaste. Therefore, blanching pre-treatment contributed to a sweeter flavour in blanched okra samples than in unblanched okra samples (Stone *et al*., 1986).

Phuoc Minh *et al*. (2019) studied the impact of blanching, drying, and storage on cinnamic acid and antioxidant activity in dried strawberries by analysing sensory attributes, particularly colour. The strawberries are dried at various temperatures, with the sensory score, particularly for colour, decreasing as the drying temperature rises. The strawberry samples dried at 50 ℃ had the highest sensory score. The finding indicated that the 50 ℃ is the optimum temperature for dried strawberry samples. It is believed that the temperature can enhance sensory qualities of dried fruits.

Moreover, Chu *et al*. (2021) conducted research on the ultrasound and curing agent during osmotic dehydration to strengthen the qualitative features of freeze-dried yellow peach slices, where the researchers conducted sensory analysis on the peach slices by evaluating several sensory attributes. The sensory characteristics such as colour, texture, odour, and overall acceptability were analysed, and the sensory ratings obtained for yellow peach slices were higher, along with the ultrasonic power, as compared to fresh yellow peach samples. Meanwhile, the ultrasound pre-treatment preserves the majority of the sensory properties of the osmotically dehydrated yellow peach slices, influencing the panellists' perspective toward a more favourable overall acceptance.

Textural analysis

The texture is one of the most important and fundamental parameters to measure since it is associated with the rheological and structural qualities of the food, which may be investigated using several textural characteristics such as hardness, adhesiveness, cohesiveness, gumminess, springiness, chewiness, and viscosity (Nieto *et al*., 2013). As shown in Figure 2, each textural characteristic has its own definition and significance, as well as differing terminology. The textural analysis is critical in determining if the fruits are considerably impacted by the osmotic process and how the osmotic process affects the fruits (Telis *et al*., 2005). During the osmotic dehydration process, the food, particularly fruits, began losing water and enhanced the uptake of solids (sugar), which contributed to the modification of textural characteristics and changed the appearance of the final goods (Prinzivalli *et al*., 2006).

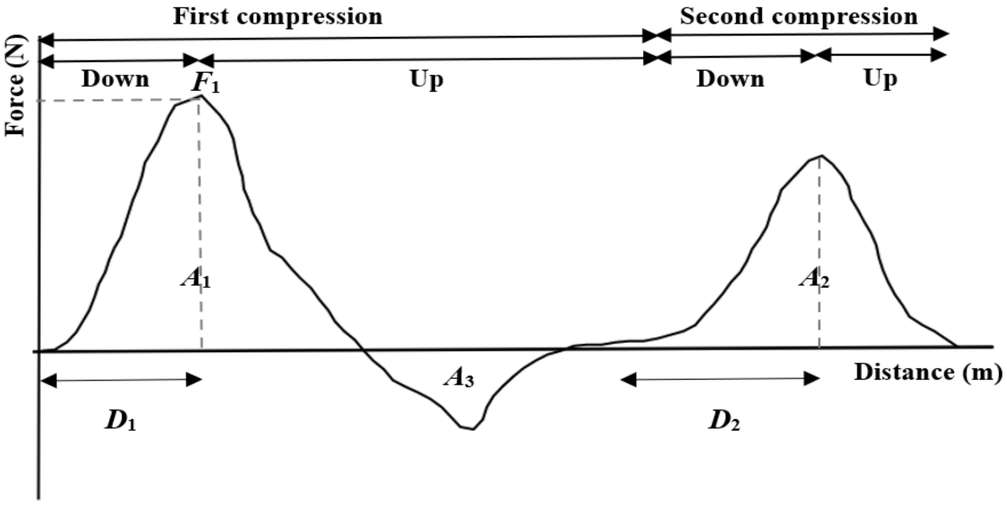

Figure 2. Illustration of the force-displacement curve derived from a double compression test of air-dried papaya using the texture analysis method (Udomkun *et al*., 2014)

Some researchers investigated the effects of textural studies for several pre-treatments on various types of fruits. Pereira *et al*. (2007) studied the textural analysis of osmotically dehydrated guava. The result indicated that the increases in calcium chloride and calcium lactate concentration boosted the osmotic dehydration process, which enhanced the guava's hardness level. Furthermore, Luna-Guzman & Barrett (2000) and Pereira *et al*. (2007) conducted numerous studies on fruits and vegetables and discovered the firming effect of calcium salt concentration on vegetable or fruit tissue, which is represented by the interaction of calcium ions with cell walls and middle lamella pectin. The development of bridges between pectin molecules toughens the tissues and enhances their resistance to deformation.

On the other hand, the freezing pre-treatment also influenced the textural characteristics of fruits. Zhao *et al*. (2014) reported the lowered hardness levels of the mango samples due to the development of ice crystals in the mango samples. Hence, the osmo-dehydrofrozen samples had considerably greater hardness than conventionally frozen ones. This finding might be likely to have contributed to sugar uptake, which improved sample hardness since sugar always improves the structural integrity of fruits.

Similarly, Ramya and Jain (2017) also found that dehydrofrozen cucumber samples showed considerably enhanced stiffness and firmness over a longer storage period. In contrast to Phuoc Minh *et al*. (2019), significant changes were observed in the texture of dried strawberries throughout the blanching method, where mechanical resistance and firmness were enhanced with a decline in the toughness of the dried strawberries. It can be concluded that various pre-treatments that are applied to osmotically dehydrated fruits can affect the textural characteristics of the fruit products.

Mayor *et al*. (2011) investigated a study on the textural quality in terms of shrinkage, density, porosity, and shape changes during the dehydration of pumpkin, where research proved that the pumpkin began to shrink along with a decrease in the volume, porosity, thickness, roundness, and weight of the pumpkin when the temperature of air drying increased to an extent since drying influences the mechanical characteristics of most fruits and vegetables. Furthermore, high temperatures are used for drying, which may cause substantial microstructural changes that can lead to textural alteration on the surface of the pumpkin. This may result in the creation of a hard outer surface layer.

Conversely, Chu *et al*. (2021) performed research on the ultrasound and curing agent during osmotic dehydration to strengthen the qualitative features of freeze-dried yellow peach slices, where the researchers conducted texture analysis by concentrating on the hardness of the yellow peach slices. The hardness values of the osmotically dehydrated yellow peach slices are raised along with the increase in ultrasound power since ultrasound is utilised throughout the penetration process in the texture analyser to ease the penetration of trehalose and retain the cellular integrity of yellow peach slices. In short, osmotically dehydrated yellow peach slices treated with 240 W of ultrasound power required more force to rupture the peach slices, which was comparable to the force required to rupture fresh yellow peach slices.

Morphological analysis

The morphological analysis is interrelated with the textural analysis since the texture influences the structural quality of the food products. Some texture characteristics of most vegetable tissues are strongly affected by cell swelling, intercellular connectivity (middle lamella), cell wall resistance to compressive forces and attraction, and other factors such as sample size, shape, processing temperature, and strain rate (Nieto *et al*., 2013).

The changes in morphological structure of osmotically dehydrated fruits due to the pre-treatments, including calcium salt treatment, blanching, freezing, drying, and ultrasound can be observed using a scanning electron microscope. Quiles *et al*. (2004) investigated the morphology and structure of osmotically dehydrated "Granny Smith" apples effected by calcium salt (Figure 3). They discovered how the calcium salts influenced the intercellular structure of the apple samples. The fresh apple samples that were treated with calcium chloride were retained without any cell damage, as illustrated in Figure 3(a). They mentioned that there was swelling and compacting of the cell wall in the treated apple sample, as shown in Figure 3(b).

Figure 3(c) also shows that the calcium salt treatment improves cellular cement while protecting cell-to-cell interaction integrity and reinforcing the middle lamella of a fresh apple sample. Fortunately, the osmotically dehydrated apple samples treated with calcium chloride demonstrated that calcium has numerous preservation effects on the cellular structure (Figure 3(d)), preventing the cells from rupturing as indicated in Figure 3(d) and 3(e). Meanwhile, Figure 3(f) depicts the effects of osmotic dehydration on apple cells, which causes wrinkles and stripes (Quiles *et al*., 2004).

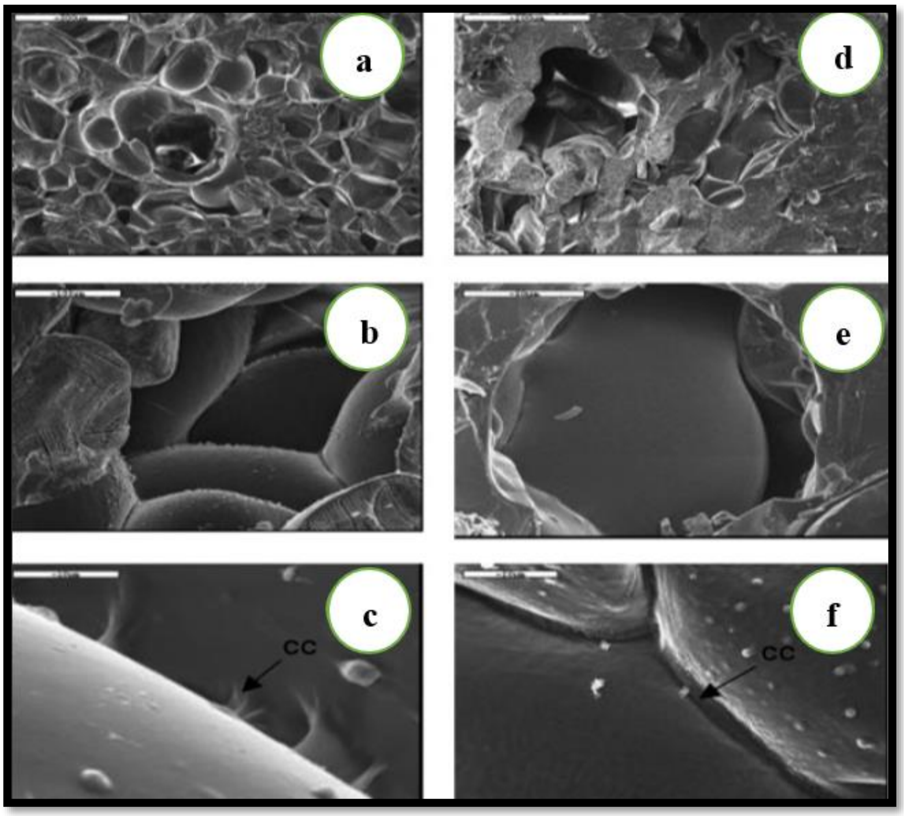

Figure 3. Morphological structure of (a) fresh apple sample treated with calcium chloride, (b) calcium chloride-treated apple sample, (c) calcium chloride-treated apple sample’s cell-to-cell interaction, (d) calcium chloride-treated osmotic dehydrated apple sample, (e) detailed information of calcium chloride-treated osmotic dehydrated apple sample, and (f) reinforced cement in an osmotically dehydrated apple treated with calcium chloride (Reproduced with permission from Quiles *et al*., 2004)

The freezing and blanching pre-treatments also influenced the morphology and structure of osmotically dehydrated fruits. Bchir *et al*. (2012) found that the freezing pre-treatment altered the cell integrations of osmotically dehydrated pomegranate seeds before and after the freezing pre-treatment. As shown in Figure 4, the morphology images between frozen and unfrozen pomegranate seeds are different. Figure 4(a) and 4(b) illustrate the fresh and frozen pomegranate seeds, respectively. Figure 4(c) and 4(d) represent osmotically dehydrated fresh pomegranate seeds and osmotically dehydrated frozen pomegranate seeds, respectively.

The morphological image showed the largely homogenous cytoplasmic membrane and cell walls (Figure 4(a)). However, the freezing pre-treatment altered the morphology and microstructure of pomegranate seeds, as illustrated in Figure 4(b), where the heterogenous cytoplasmic membrane and cell wall were observed. Interestingly, Figure 4(c) and 4(d) proved that the tissue structures of pomegranate seeds were modified by the osmotic dehydration process compared to an untreated pomegranate seed sample (Figure 4(a) and 4(b)). Due to turgor loss, frozen pomegranate seed cells were broken and irregular in shape (Bchir *et al*., 2012).

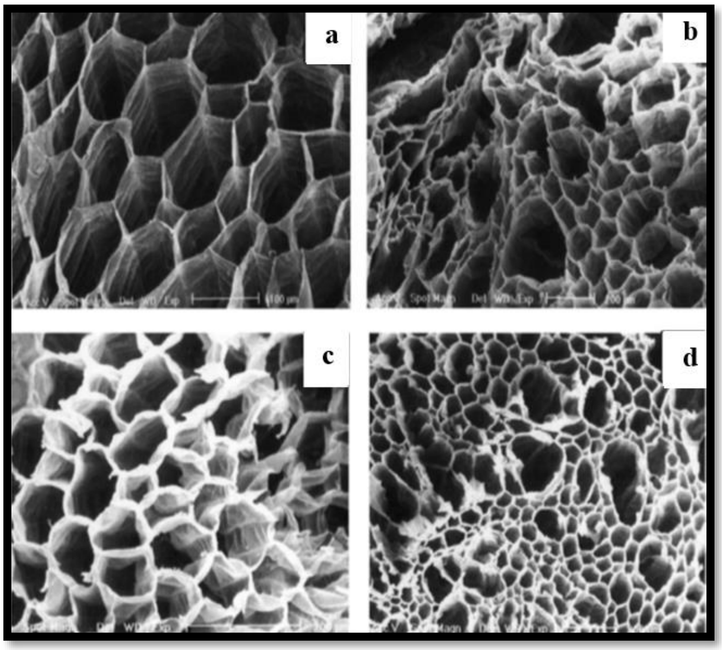

Figure 4. Morphological structure of (a) fresh, (b) frozen, and osmotically dehydrated fruits prepared with (c) fresh and (d) frozen pomegranate seeds (Reproduced with permission from Bchir *et al*., 2012)

Regardless, the blanching pre-treatment has a huge influence on cellular integrity since it inhibits the softening of fruits and vegetables. But there are fewer literature reviews on the effect of blanching pre-treatments on the structural integrity of osmotically dehydrated fruits. Del Valle *et al*. (1998) examined the impact of blanching and calcium infiltration on certain attributes such as the texture and microstructure of osmotically dehydrated apple tissues and found several changes in the structure of blanched apple tissues. An untreated, fresh apple demonstrated a homogeneous cytoplasmic membrane and cell walls. When the apple samples underwent high temperature, short time (HTST) blanching pre-treatment, the cell wall and cell membrane deteriorated, which enhanced cell detachment and cellular breakdown.

The low temperature, longer time blanched apple samples were those in which prolonged blanching time may have led to excessive cell wall detachment and disintegration owing to osmotic stress. The effects of raising the blanching temperature were comparable; however, the maximum breakdown was smaller than that of high temperature, short time blanching pre-treatment (Del Valle *et al*., 1998). On the contrary, the vacuum infiltration pre-treatment affected the majority of the cellular structure of the apple sample by assisting calcium chloride impregnation.

Lewicki and Pawlak (2003) studied the effect of drying on the morphological and microstructural characteristics of plant tissue using an optical microscope to examine and analyse the microstructure of a fresh apple and an apple that has undergone the convective drying process. However, the researchers noticed that the high temperature of the drying altered and partially denatured the tissues and cells of the fresh apple. An untreated fresh apple is illustrated a visible homogeneous cytoplasmic membrane and cell walls. When the apple samples were dried using the convective drying method, the cell wall and cell membrane degraded and began to leak, resulting in increased cell detachment and cellular breakdown, causing the apples to shrink and become smaller in size and volume (Lewicki & Pawlak, 2003).

The morphological structure of osmotically dehydrated fruits was also significantly affected by the ultrasonic pre-treatment. Fan *et al*. (2020) discovered that ultrasonic pre-treatment affected the cell integrations of osmotically dehydrated kiwifruit before and after ultrasound pre-treatment. The morphological pictures of fresh and osmotically dehydrated kiwifruits subjected to ultrasound varied.

The morphological image revealed a clearly homogenous cytoplasmic membrane and cell walls. However, the longer the ultrasound pre-treatment, the greater the effects on the morphological structure of osmotically dehydrated kiwifruits, where the heterogeneous cytoplasmic membrane and cell wall were observed. The ultrasound-osmotically dehydrated kiwifruit cells are distorted, broken, and irregular in shape due to the longer osmotic dehydration process and moisture loss (Fan *et al*., 2020).

CONCLUSION

Osmotic dehydration has emerged as an alternative method that can be used on perishable fruits to reduce the postharvest losses in the food industry as well as the mass of finished goods. However, it also has a drawback where it makes the structure, texture, and overall quality of fruits less desirable, which may be rectified by using variety of additional pre-treatments such as calcium salt treatment, freezing, blanching, ultrasound, drying, and vacuum, as well as others. Osmotic dehydration is widely performed on most fruits and vegetables, with sucrose being the most commonly employed osmotic agent since it is affordable, eco-friendly, and has the lowest molecular weight that quickly diffuses through the semi-permeable membrane of plant tissues. Moreover, calcium salts protect and preserve the fruits in terms of colour, texture, flavour, and microstructure by avoiding denaturation. However, all physical pre-treatments, including blanching, freezing, drying, and ultrasound, have both positive and negative effects on the quality of fruit samples, with all pre-treatments having an adverse impact on the textural and microstructural qualities of fruit except the ultrasound pre-treatment. The higher blanching and drying temperatures, greater ultrasound power, and lower freezing temperatures for longer times may lead to adverse effects on the fruit samples since the cells and tissues begin to denature and break, which contributes to severe textural, colour, and sensory changes.

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