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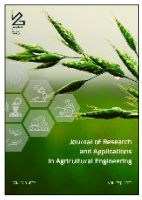

The Use of Unconventional Solutions in the Osmotic Dehydration of Food

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Osmotic dehydration is an essential process in many food materials to reduce water activity to inhibit microbial growth. This process is also used as a pre-treatment before drying to produce fruit and vegetable snacks. The most commonly used osmotic solutions are sucrose and sodium chloride, however, the use of these substances is associated with a high content of sugar and salt in the product. The use of polyols or fruit juices reduces the sugar content compared to sucrose and enables the enrichment of the product with bioactive compounds, resulting in a health-promoting snack. The article discusses the process of osmotic dehydration and the possibility of using unconventional osmotic solutions for different food products, including polyols, concentrates and fruit juices.

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1. Introduction

The main cause of fruit and vegetable spoilage is high water content. To increase their durability, many methods of food preservation have been tried and osmotic dehydration is one of them. This process is economical and is preferred over others for its vitamin, mineral, color and flavor retention properties [1]. The most commonly used osmotic solution is sucrose solution, which has been used in the production of many products, including dried and candied fruits and vegetables. Studies have shown that the combination of various osmotic agents was more effective than sucrose alone due to the mixture of solute properties. However, the use of other mixtures for fruit dehydration also has positive effects on food production, especially in terms of reducing the sugar content in products [2]. Osmotic dehydration is widely used to partially remove water from plant tissues by immersing them in a hypertonic (osmotic) solution. In this process, the driving force is the higher osmotic pressure of the hypertonic solution, which diffuses water from the tissue into the solution. At the same time, the membrane responsible for osmotic transport is not perfectly selective, which means that other solutes present in the cells can also be washed out into the osmotic solution [3]. The diffusion rate of water from any material formed from such tissues depends on several factors, including the temperature and concentration of the osmotic solution, the size and geometry of the material, the mass ratio of the solution to the material, and the degree of excitation. During osmotic treatment, the mass transfer takes place through semi-permeable cell membranes present in biological materials, which provide a predominant resistance to this process. The state of the cell membrane can change from partially permeable to fully permeable, which can lead to

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significant changes in tissue structure. During the osmotic removal of water from the product, the dehydration front moves from the surface in contact with the osmotic solution to the center, causing osmotic stress and cell disruption. The most likely cause of cell damage is a reduction in cell size due to loss of water, resulting in a loss of contact between the outer cell membrane and the cell walls [4]. Osmotic dehydration is an essential process in many food materials to reduce water activity to inhibit microbial growth. Most foods contain large amounts of water, which means they are expensive to transport, package and store. Osmotic dehydration is also recognized as an energy-saving partial dehydration method because no additional energy is required to transition the product from a liquid to a solid state. To increase the economic attractiveness of osmotic dehydration, reconcentrate the osmotic solution by evaporation or by adding fresh osmotic reagent. This can be an effective complementary processing step to thermal dehydration, if not an alternative, in the overall process of integrated food processing. Osmotic dehydration can reduce the total energy cost of the process. Products subjected to this process require shorter drying times in subsequent stages, e.g. freeze-drying. Such products also show better final quality [5].

2. Mechanism of the osmotic dehydration process

When food materials are immersed in a highly concentrated osmotic solution, a complex mass transfer process is created in which the solution flows simultaneously with a combination of drying, leaching and impregnation processes in the matrix of biological tissues. The loss of moisture from the product takes place faster in the first few hours, then the rate decreases slowly in the following hours and finally levels out [3]. Figure 1 shows the mechanism of the osmotic dehydration process. Diffusion of solute into the material is not significant at the initial stage of osmotic treatment, however, as the dehydration process continues, more solute enters the food product [6].

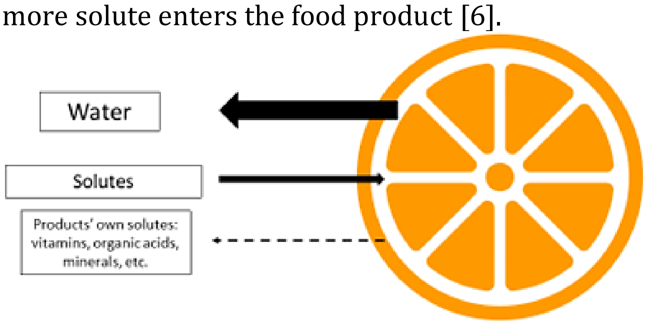

Figure 1. Mechanism of the osmotic dehydration process.
Source: Adapted based on Ramya & Jain [7].

Usually, liquid diffusion takes place in non-porous solids while capillary motion takes place in porous solids. In porous food materials, gas-filled cavities, capillaries and cell walls as well as intra- and extracellular spaces provide mass transfer pathways. The cells mainly involved in osmotic dehydration are the parenchymal cells, which consist of three parts: the extracellular volume, the intercellular volume, and the cell membrane between them. The extracellular volume includes the cell wall and the spaces between the respective cells. The intercellular volume contains the vacuole and cytoplasm. The chemical potential difference in the semi-permeable membrane between the cellular material and the osmotic solution is the driving force of mass flow, which is related to temperature and water activity [8]. The phenomena of osmotic dehydration precede the achievement of equilibrium by the water activity of both the solution and the sample. However, lower ambient osmotic pressure than the cell causes water to migrate into the cells. Cells begin to swell to a limited extent due to the rigid structure of the cell wall. The solute flows into the extracellular volume and can penetrate the cell membrane and diffuse into the intracellular volume, depending on the geometry of the solutes. When solutes penetrate the tissue, a potential difference is created in the cell membrane - hence water flows into the extracellular volume. A cell immersed in a hypertonic solution loses water. A continuous matrix capable of diffusing water and fine particles is formed due to the interconnections of the cell wall in the tissue. When the food material is immersed in a hypertonic solution, the cells in the first layer of the material are in contact with the solution and begin to lose water due to the concentration gradient between the hypertonic solution and cells, leading to material shrinkage [3]. After the loss of water from the first layer cell, a chemical water potential difference arises between the first layer cells and the second layer cells. Then the cells of the second layer start pumping water into the cells of the first layer and then shrink. Over time, the process of mass transfer and tissue contraction extends from the surface to the center of the material. Eventually, the cells in the center of the material lose water, and the mass flow likely stabilizes after prolonged liquid-solid contact. However, the cell membrane is not completely selective. Solutes such as organic acids, minerals, sugars, dyes and fragrances can flow into a hypertonic solution [9]. The dehydration front moves towards the center of the material during osmotic dehydration, leading to the breakdown of cell membranes in the dehydrated area. Water is transported through three different areas, each with its characteristic properties, i.e. water diffusion from the core of the material to the dehydration front, water diffusion through the front and water diffusion through the osmotic treated biological material into the surrounding medium. Initially, water is diffused from the outer layer of the sample into the osmotic medium, increasing thus osmotic pressure on the surface. Cell membranes begin to burst and shrink when osmotic pressure reaches a critical value. This leads to a sharp reduction in the percentage of intact cells, which is due to an increase in the cell lysis rate [6].

2.1. Osmotic dehydration in sucrose solution

The process of osmotic dehydration is the removal of water from the material, during which solids from the osmotic solution are transported to the material by osmosis. This process is most often carried out in sucrose solutions. Usually, binary solutions of sugars (glucose, fructose, trehalose, lactose, etc.)

or salts (mainly sodium chloride) are also used as osmotic media. Some characteristics of the solution are required for use as an osmotic medium. Variables such as variety, maturity, pre-treatment, temperature and concentration of the osmotic agent, material geometry, mixing, the ratio of food pieces to the osmotic solution, additives, physicochemical properties and structure influence the kinetics of mass transfer during osmotic dehydration [10]. The solute should be cheap and have high solubility in water and a positive effect on the organoleptic properties and stability of the final product. Thus, sucrose is usually chosen as the solute, but one disadvantage is the high viscosity of concentrated solutions. Glucose solutions are often used, and the results of mass transfer processes are compared with those in which a sucrose solution is used. Physical properties indicate that at high concentrations glucose solutions have both higher osmotic pressure and water activity, and at the same time they are characterized by lower solubility and kinematic viscosity than sucrose solutions [11].

2.2. Unconventional osmotic solutions

Considering that relatively high consumption of sugar may have a negative impact on human health, attempts are made to look for alternative solutions that can be used for osmotic dehydration. The osmotic factor may be coconut sugar, beet molasses, and stevia. Natural sweeteners are also used [1]. Jaggery, i.e. unrefined sugar produced by traditional methods from sugar cane juice and honey, the use of which is associated with numerous health benefits. They are less caloric, have a lower glycemic index, and also have anti-caries and antibacterial properties. Thanks to these advantages, they can be used on a small scale at home as well as in mass production. Solutions from concentrated fruit juices are also used, such as apple, banana, peach, and grape, as well as juices obtained directly from fruits, e.g. chokeberry with proven beneficial properties for human health due to the high content of anthocyanins and other bioactive substances [3]. Scientific studies have confirmed the beneficial effect of using such solutions during the osmotic dehydration of zucchini and carrots. The use of aronia juice significantly increased the content of polyphenols and the antioxidant capacity of the products. In addition, during the dehydration process, the solids of the raw materials were transferred from the osmotic solution to the raw material, causing a decrease in their concentration. This was due to the selective transport of polyphenols from the osmotic solution to the material. It was found that compounds with lower molecular weight and lower antioxidant capacity present in concentrated chokeberry juice had a stronger effect on the exchange of compounds during the process in carrot and zucchini [11]. The use of such solutions makes it possible to increase the value of fruit and vegetables thanks to minerals, vitamins and other natural substances that are contained in fruit or vegetable juice concentrates [3].

Table 1. Examples of the use of unconventional substances for osmotic dehydration of fruits.

Type of osmotic solution		**Application**	**Reference**
Polyols	Xylitol, erythritol	Quince	[12]
	Mannitol and sorbitol	Strawberry	[1]
	Maltitol, inulin and oligofructose	Apple	[13]
Fruit or vegetable juice concentrates	Chokeberry, strawberry and cherry juice	Strawberries	[2]
	Chokeberry juice	Zucchini, carrots	[11]
	Chokeberry juice	Apples	[14]
	Apple Juice	Cherries	[15]
	Beetroot juice	Apples	[16]
	Pear, apple, cherry, pineapple, blackcurrant and chokeberry juices	Quince	[17]
Fructooligosaccharides	Sucrose, fructose, glucose	Cherries, blackcurrants	[18]
	Yacon, sucrose	Bananas	[19]
	Sucrose	Apricot, chokeberry	[20]

Application of osmotic dehydration in food production

Consumers are increasingly paying attention to what they eat, nutritionists encourage the consumption of vegetables and fruits, while food technologists are developing solutions that can ensure longer shelf life of these raw materials. The high nutritional value of products is a key element that can be obtained using osmotic dehydration. The product attracts not only with its quality (nutritional and health value) but also with its attractiveness (taste, smell, appearance) [21]. The use of the osmotic dehydration process makes it possible to obtain many fruit, vegetable or fruit and vegetable products, which are shown in Figure 2. These include candied fruit and dried snacks, etc. In addition, the osmotic dehydration process in fruit reduces post-harvest losses and allows preservation of the characteristics of the fruit, such as color, aroma, texture and nutrient content [6].

Figure 2. Examples of fruit products obtained using the osmotic dehydration process [22].

Various methods can be used to intensify the osmotic dehydration process, such as pulsed electric fields, high pressure, vacuum, microwaves, centrifugal force or ultrasound [23]. The osmotic dehydration technique was most often used in the development of new products because it affects the nutritional and sensory properties of fresh fruit and vegetables [24, 25]. In addition, the osmotic solution maximizes the sugar-to-acid ratio and increases the stability of pigments and texture during drying and storage. The sugar uptake of low molecular weight saccharides (glucose, fructose and sucrose) is high due to the maximum diffusion of the molecules. This method ensures gentle processing of fruit and vegetables, due to their greater sensory similarity between dried and natural products [6, 24]. However, dehydration temperatures above 45°C cause thermal tissue damage, flavor deterioration, and enzymatic browning. Because osmotic dehydration partially removes water, resulting in a medium-moisture product has a lower water activity at which most of the chemical, physical and biological spoilage effects of the food are stopped [18]. In addition, the osmotic pre-treatment provides benefits such as energy saving and reduction of thermal damage, color and taste, as well as delaying enzymatic browning. We have problems with food waste in the world, caused by excessive, ill-considered purchases related to the short shelf life of food products. The use of such a method can prevent food waste because dehydrated raw materials have a much better shelf life [26]. These partially dehydrated vegetables and fruits are used in products such as yogurt, ice cream, desserts and confectionery. In addition, the dried product can be used as a snack or component of cereal flakes for direct consumption [25]. Some researchers have already described that osmotic dehydration can be very beneficial for raw materials such as sourdough, banana, jackfruit, pouteria sapota, mango, guava, papaya, pineapple, ginger, carrot as well as seafood and meat [6, 24, 27]. The main advantages of using osmotic dehydration are lowering the temperature of the process temperature, the sweeter or saltier taste of the dehydrated product and reducing energy consumption by 20-30% and shortening [28]. The osmotic dehydration process improves the nutritional, functional and organoleptic characteristics of the product. It also increases the sensory similarity between dehydrated and natural products [29]. The remaining osmotic solution can also be used in the beverage industry, thus increasing the economy of the process, or it can be reused for further drying [21, 24]. The osmotic dehydration process does not require advanced equipment and can be carried out in open containers or be one of the stages of the production process as a pre-treatment, e.g. before the drying process [30].

Conclusions

Osmotic dehydration is widely used to partially remove water from plant tissues by immersing them in a hypertonic solution. Usually, sucrose or sodium chloride is used but unconventional solutions are beneficial due to a few aspects. Polyols are natural sweeteners and have a low-calorie content, unlike traditional sweeteners such as sucrose or glucose. Their consumption does not cause caries and does not negatively affect tooth enamel. These are substances that do not raise blood sugar levels, which is why their consumption is a good alternative for people suffering from diabetes. Dehydrated products are characterized by a high content of sugars, so to avoid this, the use of a solution with the addition of polyols during the osmotic dehydration of fruits is very beneficial. Concentrates or fruit and vegetable juices also have many advantages, because they are a source of valuable substances (e.g. vitamins, polyphenols), which during osmotic dehydration can pass into the dehydrated product, increasing its nutritional value. In addition, the use of concentrates or fruit juices can also naturally preserve or change the color of the fruit, which can affect the attractive appearance and positive consumer evaluation. Fruits and vegetables are interesting, but perishable food products, therefore ways to preserve them using the osmotic dehydration process with unconventional solutions such as polyols, concentrates and fruit juices are tested.

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