Innovative technology of processing berries by osmotic dehydration

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Abstract. The present study is devoted to the influence of osmotic agent type and of its concentration on processing fresh berries with subsequent freezing. Freezing berries without preliminary protection destroys their texture, and during defreezing berries lose their consumer properties and vitamin content. The study describes the physical and chemical processes of osmotic dehydration: crystallization temperature; sucrose syrup concentration; changing the mass; frozen moisture amount; water activity; change of the mass fraction of mono-, disaccharides and vitamin C in the berries. As a result, crystallization temperature of dehydrated berries was calculated: from -1.1°C to -2.6°C (60°Brix) and from -1.7°C to -4.8°C (70°Brix). Frozen moisture amount was estimated at 83.2%-92.8% (60°Brix) and 52.2%-87.95% (70°Brix), water activity was 0.9756-0.9891 (60°Brix) and 0.9551-0.9838 (70°Brix). The obtained data allowed determining that the amount of monosaccharides in frozen berries which were preliminarily osmo-dehydrated with 70°Brix sucrose solution rose up to 20%, and the amount of vitamin C to 14.8% (compared with freshly frozen berries). Osmotic dehydration with sucrose solution of specified concentration protects the smooth texture of berries and preserves their organoleptic properties and valuable nutritional composition.

1. Introduction

Berry products are a widely-known source of many nutrients, including potassium, fiber, vitamin C and folic acid. Nutrients are vital for good health and maintenance of the immune system, for instance, potassium contained in various fruit and berries reduces the risk of heart disease and stroke [1, 2]. This produce is low in fat and calories, is a good source of fiber and contains antioxidants that protect the human body from cellular damage caused by free radicals. Fiber helps regulate digestion and reduce the risk of cardiovascular diseases through its cholesterol-lowering mechanisms. Vitamin C is an important antioxidant that protects cells from free radical damage [3, 4].

Berries belong to the category of especially perishable foods with a short shelf life, since their protective function, namely, the wax coating, is very thin and cannot protect against water evaporation, mechanical damage and penetration of various microorganisms [5, 6, 7, 8, 9, 10, 11, 12]. Therefore, to properly preserve the plant product, namely fruit and berries, without losing their valuable vitamin
complexes and organoleptic properties, it is necessary to apply new technologies or combine traditional methods with new methods.

The present study aims at suggesting ways to preserve the entire range of nutrients, to protect the delicate structure of raw produce before processing and to make fruit and berries products more accessible at any time of the year. Processed products are of great importance for the supply of Russia’s population, especially of the northern regions, the army, the fleet and people on long expeditions. Therefore, osmotic dehydration with hypertonic sucrose solution will help protect raw materials from rapid spoilage and preserve the entire range of nutrients.

The method of processing raw materials in hypertonic sucrose solutions was tested on many types of fruit [5, 13, 16, 18, 19]. During scientific studies of osmo-dehydrated fruit and berries, the best results were obtained on tested plums, pears, apples, apricots, pineapples, peaches, bananas, kiwis, cranberries, blueberries, pomegranate seeds, garden strawberries, guavas and quince [3, 7, 13, 14, 16, 17, 18, 20, 21, 22, 23, 24, 25, 26]. Less effective results were obtained on small fruit types (cherries and sweet cherries) [17, 19]. To date, osmotic dehydration of fruit and berry raw materials by a hypertonic aqueous solution of sucrose is fully studied by Russian and foreign authors.

Dehydration means that the food product is immersed in a hypertonic aqueous solution of different concentrations and low water activity [24, 27, 28, 29]. It is scientifically proved that dehydration with an osmotic agent is the main method for reducing water activity in producing food with intermediate moisture [11, 17].

Osmotic dehydration describes the stage of preparation for further processing of food products with simultaneous transient loss of moisture and an increase in solids when immersed in a hypertonic sucrose solution, which leads to partial drying and improvement in the overall quality of food [10, 15, 30].

The main task is to conduct osmotic dehydration with hypertonic sucrose solution without loss of organoleptic qualities and nutritional value, and reducing the water content by dehydrating with sucrose solution will reduce water activity, thereby making the product inaccessible for the development of microorganisms [17, 27, 28, 29].

An important parameter is water activity which affects microbiology and the shelf life of osmo-dehydrated produce, and is defined as the moisture content of the food product. This is confirmed by the authors [6, 10, 14, 22, 27], who studied water activity and dry matter content of osmo-dried and osmo-lyophilized fruits.

The process of osmo-dehydration is also influenced by solubility, molecular weight, physico-chemical properties and by the ionic state of the solute [27]. Osmo-dehydration serves as a driving force for counter-flows of solute and water, and measures the degree of water loss and absorption of solid particles [20, 29]; all this significantly affects the organoleptic and physical properties of the ready-made product. Besides, an important criterion is the compatibility of the solute with the components of the hypertonic solution [19, 20]. An osmotic agent with a lower molecular weight can easily penetrate into the cells of plant materials as compared to a hypertonic solution with a higher molecular weight [29, 31].

2. The object of the study
The objects of research were fresh Russian berries: raspberry, strawberry, blackberry and black currant bought at the market, and sucrose solution: water and granulated sugar.

3. Materials and methods

3.1 Effect of concentrations of hypertonic sucrose solution on the intensity of osmotic dehydration
When studying the effect of the concentration of hypertonic sucrose solution on the intensity of osmotic dehydration, the berries (with the non-edible part removed) were weighed, immersed in hypertonic sucrose solution with 60°Brix and 70°Brix concentration at the ratio of 1:5 and dehydrated for a predetermined period (depending on the structure of the berries). Then, the berries were removed from
the solution, dried on filter paper and weighed for determining the change in weight compared to the initial weight.

The time of keeping the berries in the solution was determined by the expert method with regular weighing; in case of no mass changes, the experiment continued.

Figure 1 shows the histogram of the mass loss (compared to the initial weight of the berries). Curves 1 show changes in weight when the 60°Brix solution was used as an osmotic agent, and Curves 2 correspond to the 70°Brix solution.

![Graphs showing mass change of osmo-dehydrated berries at a certain interval](image)

**Figure 1.** Mass change of osmo-dehydrated berries at a certain interval

The process of dehydration in the investigated berries progresses in stages: first, the hypertonic aqueous solution penetrates the skin and then the flesh. As seen from the histogram figure 1, osmotic dehydration begins in almost all types of berries immediately after they are immersed in a concentrated hypertonic aqueous sucrose solution at different concentrations. The mass change in berries has different indicators due to their structure. Strawberry dehydration is most dynamic within 4 hours, then the process slows down and mass increases; this is due to the partial diffusion of the osmotic agent into the cell tissue [1, 21, 22, 27]. Raspberry dehydration occurs within 20-30 minutes, and after 120 minutes, the mass begins to grow; this due to the fact that raspberries have very tender flesh and a less dense structure compared to other berries. Blackberry mass change continues for 6 hours, and, as with raspberry, there is a sharp increase in weight. Black currant mass change begins only after 2 hours, while osmotic dehydration takes about 7 hours; a slight increase in mass begins afterwards; such long process is due to the fact that black currant has dense skin structure.

The research revealed that the hypertonic solution concentration significantly affects the degree of osmotic dehydration of berries [6]. The most intensive osmotic dehydration in combination with the optimal dehydration period was achieved using 70°Brix solution, which is confirmed by a decrease in the mass. Moisture loss in strawberry was 16% (60°Brix) and 21% (70°Brix) after 6 hours, in raspberry it was 4% (60°Brix) and 7% (70°Brix) in 1.5 hours; in blackberry it was 3% (60°Brix) and 6% (70°Brix)
after 6 hours; in black currant it was 4% (60°Brix) and 8% (70°Brix) after 7 hours. As a result, the use of hypertonic sucrose solution at the given concentration of 60°Brix means less moisture loss in the berries.

An increase in time leads to an increase in moisture yield, and a change in the ratio of berries and hypertonic solution leads to an increase in the time range, which affects the quality of the ready-made (dehydrated) product [11, 12].

It was also found that an increase in the duration of osmotic dehydration is not advisable, because with a longer period of dehydration, the berries are deformed, the sensory indicators change for the worse, namely, the shape and texture change, and the berries become soft, which is not acceptable [5, 10, 13, 16].

The research revealed that the appropriate time for dehydration of berries in concentrated hypertonic sucrose solution is determined by the structural features of berry tissue aging. The most mature berries with a more delicate structure require the minimum time of dehydration.

3.2 Determining the temperature of moisture crystallization point

After osmotic dehydration in hypertonic sucrose solution at the given concentration, the berries were frozen, and the point of moisture crystallization was determined.

One of the characteristics of foods subject to freezing is the cryoscopic temperature [11, 12, 32] determined in the water crystallization process. The data obtained is necessary for calculating the amount of frozen water, and water activity.

Detection of the cryoscopic temperature of berries osmo-dehydrated with hypertonic sucrose solution was carried out by thermal analysis based on temperature-time curves. The berries were frozen with the help of specialized equipment, the cryoscopic temperature was calculated and the kinetic curves were obtained that characterize the point of moisture crystallization of strawberry, raspberry, blackberry and black currant after osmotic dehydration with hypertonic sucrose. For comparison and for more accurate results, natural fresh berries were taken as the control sample. The obtained data are presented in figure 2.

![Figure 2. Effect of osmotic dehydration of berries on cryoscopic temperature (Tkr)](image)

The temperature of water crystallization point in strawberry was -1.8°C (60°Brix) and -2.7°C (70°Brix); in raspberry, it was -2.6°C (60°Brix) and -2.9°C (70°Brix); in blackberry, it was -1.1°C (60°Brix) and 1.7°C (70°Brix); in black currant, it was -2.5°C (60°Brix) and -4.8°C (70°Brix); this is significantly lower than in the control samples (-0.7°C and -1.8°C, respectively).

The data obtained by the authors indicate that berries osmo-dehydrated with hypertonic aqueous sucrose solution at the 60°Brix concentration contain a greater amount of moisture in relation to berries dehydrated at the 60°Brix concentration. The experiment revealed that berries osmo-dehydrated with hypertonic aqueous sucrose solution at the 70°Brix concentration better maintain structural integrity and reduce the microbiological load.
Based on water crystallization point, the amount of frozen moisture (WL, %) and water activity (Aw) in osmo-dehydrated berries were determined; the data obtained are presented in figures 3 and 4.

Consequently, the obtained data revealed that the cryoscopic temperature of the berries osmo-dehydrated at the 70°Brix concentration ranges from -1.7°C to -4.8°C, significantly differing from that of berries dehydrated at the 60°Brix concentration – from -1.1°C to -2.6°C. The amount of crystallized moisture at the 70°Brix concentration decreased to 40%, at the 60°Brix concentration it decreased to 36% in accordance with the control sample. The data obtained on the indicators of water activity in berries osmo-dehydrated at the 60°Brix concentration decreased to 1.36%, and at the 70°Brix concentration it decreased up to 3% in comparison with the control sample, which indicates the advantage of a higher concentration of hypertonic aqueous sucrose solution.

4. Mass fraction of soluble carbohydrates in the berries

The main component of taste in both fresh and processed berries is mono- and disaccharides; this component is one of the main criteria for berries before freezing. The authors carried out research on the content of soluble carbohydrates in both fresh, fresh frozen and frozen berries, osmo-dehydrated with hypertonic sucrose solution at the given concentrations.

The studies revealed that the content of mono- and disaccharides in frozen berries with preliminary osmotic dehydration at 60°Brix increased to 33.6% compared with fresh berries and up to 12% compared with fresh frozen ones figure 5. In berries dehydrated at 70°Brix before freezing, the content of mono- and disaccharides increased to 43% compared with fresh berries, up to 21% compared with fresh frozen berries and 20% compared with berries dehydrated at 60°Brix.

Further, the frozen berries osmo-dehydrated with hypertonic aqueous sucrose solution were studied in regard to their vitamin C content, since vitamin C is the main food source for maintaining the normal metabolic process. Figure 6 presents data on changes in vitamin C in osmo-dehydrated frozen berries.

The obtained results revealed that the most significant losses of vitamin C amounted to 56% in fresh frozen berries, to 39% in berries dehydrated at 60°Brix and to 33% at 70°Brix in comparison with control fresh berries. A more positive trend in the preservation of vitamin C is traced in previously osmo-dehydrated frozen berries. As a result, in berries osmo-dehydrated at 60°Brix, up to 11% of vitamin C was preserved, and at 70°Brix this index was up to 15% (up to 5% between given concentrations).
Thus, the results obtained by the authors prove that using hypertonic aqueous sucrose solution at the higher concentration (70°Brix) best preserves vitamin C.

**Conclusion**

The relevance of the research lies in the need to preserve the entire complex of nutrients and organoleptic indicators, for which the combined method of processing raw berries is to be used (namely, preliminary osmotic dehydration with hypertonic aqueous sucrose solution at given concentration and subsequent freezing) which will make the product more accessible in the non-seasonal period.

In this regard, the present research offers the best method of obtaining high-quality and safe frozen berry product – preliminary osmo-dehydration with hypertonic sucrose solution, which preserves high organoleptic characteristics and the original nutritional value of the product.

Summing up the research, it can be concluded that preliminary osmo-dehydration of berries with hypertonic aqueous sucrose solution at the concentration of 70°Brix before freezing has a low effect on vitamin C loss (33%); the disaccharide content increases (43%) due to a significant decrease in sucrose. The cryoscopic temperature of berries osmo-dehydrated at 70°Brix is lower (from -1.7°C to -4.8°C) in contrast to the control samples, which contributes to a better integrity of the berries due to fewer ice crystals forming. Thus, the amount of crystallized moisture decreases to 40%, and water activity decreases up to 3%. The resulting product contains less moisture, which is significant for microorganisms’ development during storage. Consumption of berries processed in the combined technology is nutritious, beneficial and does not require additional control over caloric intake.

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