Research article

Mass transport and changes in the saccharide profile during osmotic dehydration of apricot and chokeberry fruits

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Abstract: *The aim of the study was to determine the effect of osmotic dehydration in sucrose solution on the level and profile of the main saccharides in frozen chokeberry and apricot. A 50°Bx sucrose solution at a temperature of 25, 35, 45 and 55°C was used in the tests. The influence of temperature and dehydration time on the dry matter content in the tested fruits was demonstrated. Both in apricot and chokeberry the highest increase was recorded in the first hour of the process, for apricots to the level of 25.1-32.4%, for chokeberry 30.4-33.4%. The use of the highest temperature (55°C) increased the content of glucose and fructose while reducing the amount of sucrose (hydrolysis); at 25-35°C the opposite effect was obtained. At low temperatures, chokeberry was not very susceptible to migration of sucrose. Also, the transport of water was not intense. There was no correlation between the temperature of the process and the increase in dry matter in the sample. The greatest loss of water, i.e. 1 g H_2O/g i.d.m., occurred after five hours at 55°C. Under analogous conditions, apricots showed a higher water loss, at the level of 4.68 g H_2O/g i.d.m. At 25°C, after the first hour of dehydration, the energy value of saccharides in apricots was 315 kJ/100 g; at 55°C, after 3÷5 hours it fluctuated around 500 kJ/100g. Dehydrated chokeberry was characterized by approx. 1.5÷2 times lower energy value than apricot.*

Keywords: *osmotic dehydration, saccharides profile, apricot, chokeberry.*

Introduction

Osmotic dehydration is one of the methods of extending the shelf life of fruits and vegetables. It is carried out by immersing the material in a concentrated solution of an osmotic agent. It is a method that does not require large amounts of energy, largely preserves the original characteristics of the raw material (during osmoconcentration there is no phase change of water, which reduces the risk of adverse changes), protects the material to some extent, and also reduces the time and reduces the adverse effects of convective drying which is often the next main stage of food preservation [1, 2]. Due to the use of osmotic dehydration, changes in the appearance and colour of the raw materials are clearly less noticeable; however, this technique may change the structure of cell membranes [3].

Osmosis allows the components of a hypertonic solution to diffuse through the semipermeable membranes. During osmosis, fresh fruit and vegetables give water to the solution in which they are immersed, while particles from the osmotic solution penetrate the tissue. In the case of fruit, sucrose is most often used, in the case of vegetables and meat it is salt [4], although there have also been studies using salt in dehydrating apples [5]. For dehydration, you can also use fruit juices [6], glucose [7], sorbitol [4], glycerol [8], corn syrup, starch solution [9], solutions with the addition of fruit extracts [10], oligosaccharides [11] and sucrose with selected salts [12].

The transfer of the osmotic agent may be favourable or unfavourable depending on the substance used. If, for example, a fructooligosaccharide solution is used, the penetrating FOSs confer favourable prebiotic characteristics to the material to be dehydrated. On the other hand, the use of popular sucrose causes that the migrating sugar increases the energy value of the product, which is undesirable [13].

Not only water migrates but also mass transport also takes place. Thus, the substances in the sample diffuse into the hypertonic solution. This enriches the solution with valuable ingredients from fruits or vegetables, which allows the hypertonic solution to be used as a valuable ingredient for the production of other products like fermented beverages [14].

The dewatering process is influenced by many parameters such as: temperature, shape and thickness of the raw material, solution viscosity, duration of the process. The osmosis conditions depend on the osmotic factors and raw materials used. The final effect to be achieved is also important. For example, increasing the temperature may cause faster dehydration and shortening of the process time, but may also deteriorate the product form [15]. Temperature rise also affects the saccharide profile of the material to be dehydrated; it intensifies the migration of the osmotic substance to the tissue. However, when the temperature is too high, the osmotic factor (e.g. sucrose) may decompose, increasing the content of hydrolysis products (glucose, fructose) [13].

The aim of the study was to assess the effect of osmotic dehydration on the amount and profile of saccharides in chokeberry and apricot fruits, which were dehydrated in a concentrated sucrose solution.

Experimental

Materials

Frozen chokeberry fruit (whole; average diameter – 11 mm) and frozen apricot fruit (seedless; average diameter – 47 mm , average height – 42 mm) purchased from Cajdex Sp. z o.o. (Lodz, Poland) were used. The material was stored frozen (-18°C).

Reagents used in the tests: sucrose (Krajowa Spółka Cukrowa SA, Toruń, Poland), calcium carbonate (POCH SA, Gliwice, Poland), Amberlite IR-120 cationite (Rohm and Haas, Philadelphia, USA), Amberlite-67 anionite (Rohm and Haas, Philadelphia, USA).

Methods

Osmotic dehydration

For both fruits, the preparation for dehydration was similar, except that the apricot was cut into quarters.

Ten screw cap containers were prepared; 20±3 g of fruit (previously thawed for 30 minutes at room temperature) were placed in each container. Then fruits were flooded with a 50°Bx sugar solution in an amount 4 times greater than the mass of the sample. The containers were placed in a shaker water bath (GFL, Burgwedel, Germany). Dehydration process was performed for max. five hours at 25, 35, 45 and 55°C. Two containers were removed every hour. Then the fruits were separated from the syrup on a sieve, washed twice in distilled water and dried on tissue paper. Each sample was placed in a polyethylene bag and stored in a freezer.

Determination of dry matter

The fruit was ground in a mortar; then a sample weighing about 2 g was taken. It was placed in weighed vessel and mixed with sand. The weighing vessels were placed in a vacuum oven (MEMMERT GmbH + Co. KG, Schwabach, Germany) set at 70°C; they were dried 18 hours. The samples were then placed in a desiccator (1 hour) and weighed.

The calculations were made using the formula:

$$X = \frac{m_k - m_n}{m_o - m_n} \times 100$$

where:

X – dry matter [g/100g],

m_n – weight of the vessel [g],

m_o – weight of the vessel with sample before drying [g],

m_k – weight of the vessel with sample after drying [g].

Determination of water loss and solids gain

The amount of water removed from the fruit (WL) and solids gain (SG) were calculated using the following formulas:

$$WL = \frac{m_o(1 - S_o) - m_k(1 - S_k)}{m_o S_o}$$

$$SG = \frac{m_k S_k - m_o S_o)}{m_o S_o}$$

Where: SG – solids gain [g/g i.d.m.],
m_o – initial sample weight [g],
m_k – sample weight after dehydration [g],
S_o – initial dry matter content [g d.m./g],
S_k – final dry matter content [g d.m./g].

Chromatographic analysis

From each sample of fruit crushed in a mortar, approx. 5÷6 g were weighed into a beaker. 0.5 g of calcium carbonate and 50 mL of distilled water were added to the fruit and mixed. The sample was brought to the boil, cooled to room temperature, and set aside for 10 minutes. After this time, the mixture was quantitatively transferred to 100 mL volumetric flask and made up with distilled water. After mixing, the sample was filtered (filter paper). The filtrate was collected in sealed plastic tubes and stored in a freezer. Prior to HPLC analysis, columns filled with a mixture of cation exchanger and anion exchanger (1:2) were prepared and the extracts (5 mL) were passed through them. The first 3 mL was discarded, the remaining filtrate was analyzed by HPLC.

The chromatographic analysis was performed using a Knauer chromatograph (Germany) with an Aminex HPX-87C column, 8x300 Bio-Rad (Bio-Rad, Richmond, USA); column temperature: 85ºC, mobile phase: water, flow rate: 0.5 mL/min, injection volume: 20 µl, detector: refractometric, software: EuroChrom 2000.

Calculations and graphic processing

The preparation of figures and the calculation of standard deviation were performed using Excel software.

Results and Discussion

The course of fruit dehydration from the point of view of dry matter content is shown in Figure 1. The influence of temperature on the increase of its level is visible. The greatest increase was demonstrated in the first hour of the process; in the case of apricots, for temperatures from 25 to 55°C, the dry matter content ranged from 25.1 to 32.4% (initial 9.3%). Conducting dehydration in the following hours did not bring any major changes. The highest value, at the level of 39.8%, was obtained after five hours of dehydration at 55°C. In the case of chokeberry, the values obtained in the first hour of the process are in the range of 30.4-33.4%. There was therefore a slight increase compared to the initial value (28.1%). The highest dry substance content, i.e. 42.2%, was obtained after five hours of dehydration at 55°C. In all other cases, the dry matter was below 37%. In the experiments, temperatures were used for which the unfavorable quality changes of the dehydrated material are not too intense yet; the upper value of these temperatures is estimated at about 50°C [8].

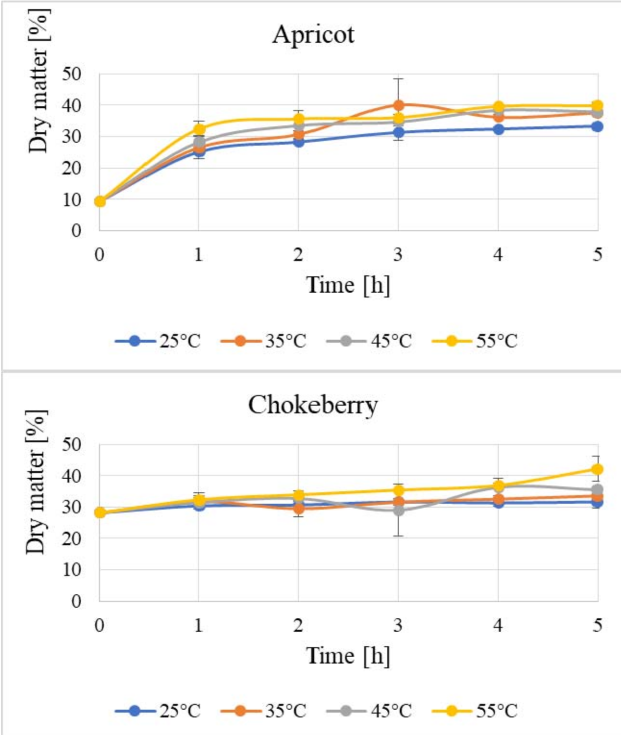

Figure 1. The content of dry substance in fruit osmotically dehydrated in a sucrose solution at various temperatures

The values of the proportion of individual saccharides are significantly different from the sugar profile for the raw material. Figure 2 shows the sugars content per product weight. A radical increase in the sucrose content is visible; at 25°C, after the first hour, it reaches the level of 15.4 g/100 g, the maximum is 27.2 g/100 g (5 h, 35°C).

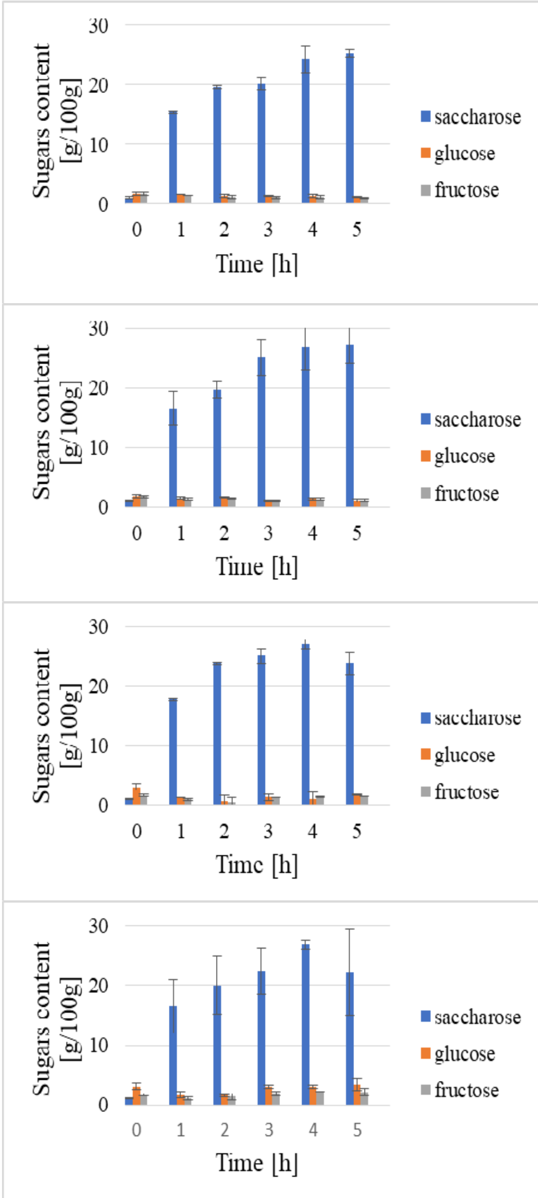

Figure 2. Changes in the content of individual saccharides in apricots, depending on the dehydration time at different temperatures, with the use of sucrose solution

The high proportion of sucrose is a known, unavoidable consequence of dehydration carried out in sucrose solution [16, 17]. In the case of the two lower temperatures, there was a constant increase in the sucrose content in the fruit, but for the higher temperatures, after the fourth hour, there was a clear decrease in its content. The greatest increase in glucose content was demonstrated during dehydration at 55°C after five hours. A higher fructose content was also observed at this temperature (at 25 and 35°C, the glucose and fructose content gradually decreased). This phenomenon was undoubtedly related to the hydrolysis of sucrose in the acidic environment of the fruit. Piasecka et al. [15] observed a similar relationship during dehydration of cherries and blackcurrants in fructooligosaccharides (FOS) solution – after increasing the temperature of the process to 60°C, the amount of FOS in the hypertonic solution decreased, and the content of fructose and glucose in the fruit increased.

The fact that the raw material was frozen was undoubtedly also a factor contributing to the migration of sucrose to the tissue. Freezing destroys the structure of the tissue and the penetration by osmotic agent is easier.

The following graphs show the mass transport between the solution and the fruit. Figure 3 shows the water loss in apricots. Regardless of the process temperature, the highest loss occurred in the first hour of dehydration; it ranged from 2.96 for 25°C to 4.66 [g H_2O/g i.d.m.] (i.d.m. = initial dry matter) for 55°C – it increased with increasing temperature (this dependence on temperature was also observed by Ruskova et al. [8]). The phenomenon of the most intense water migration in the first hour of the process is also characteristic of other raw materials, such as apple, pumpkin, mango, pear [12, 18, 19, 20].

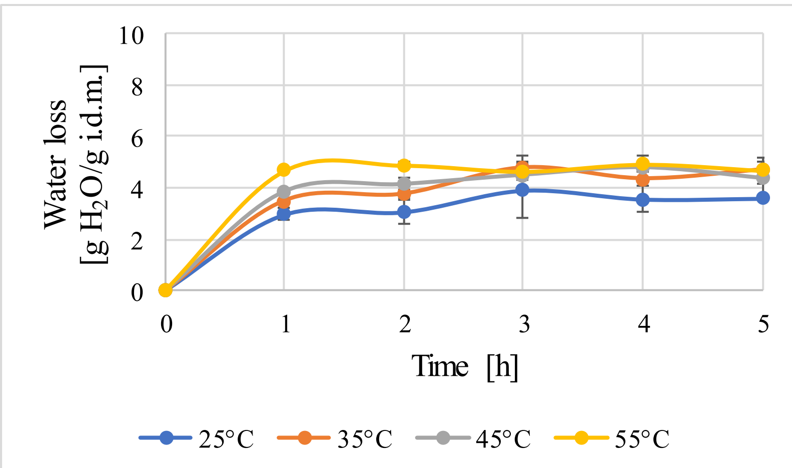

Figure 3. Water loss in apricot dehydrated in sucrose solution at different temperatures

The increase in solids gain (Figure 4) was lower than the loss of water; relatively similar at all temperatures. The longer the process lasted, the greater was the increase in dry matter, however, the most intense was recorded in the first hour, regardless of the temperature; it was within the range of 1.28÷1.45 g/g i.d.m. In the studied case, the increase in dry matter was higher than that obtained for a frozen apple (fruit frequently subjected to osmoconcentration) by Taiwo et al. [21] – about 0.9 g/g i.d.m. (50°Bx, 40°C). However, the obtained values were lower than those obtained by Kowalska et al. [19] for frozen pumpkin (1.92 g/g i.d.m. after dehydration in 61.5°Bx sucrose solution, 30°C).

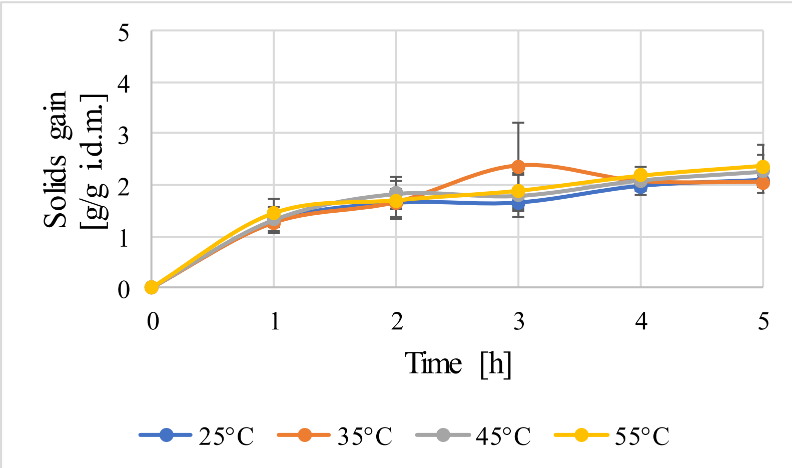

Figure 4. Solids gain in apricot dehydrated in sucrose solution at different temperatures

The dehydration process in the case of chokeberry led to obtaining a product with a different saccharide composition (Figure 5). The highest proportion of sucrose was demonstrated in the fifth hour of dehydration at 55°C (1.36 g/100 g). For lower temperatures, the sucrose content was below 0.3 g/100 mL. Chokeberry is therefore not as susceptible to migration of sucrose as apricot, especially at lower temperatures. The increase in the dehydration time, regardless of the temperature used, increased the glucose level from 4.35 g/100 g in the raw material to 4.79÷6.79 g/100 g after five hours of dehydration (in the tested temperature range). Fructose is the second most saccharide found in chokeberry. Its level in the raw material was 3.91 g/100g; after five hours it ranged from 4.45÷6.39 g/100 g for different temperatures. The sorbitol content decreased from 7.16 g/100 g in the raw material to 6.84 after five hours at 25°C and 5.52 at 55°C. This may be associated with the migration of sorbitol to the hypertonic solution.

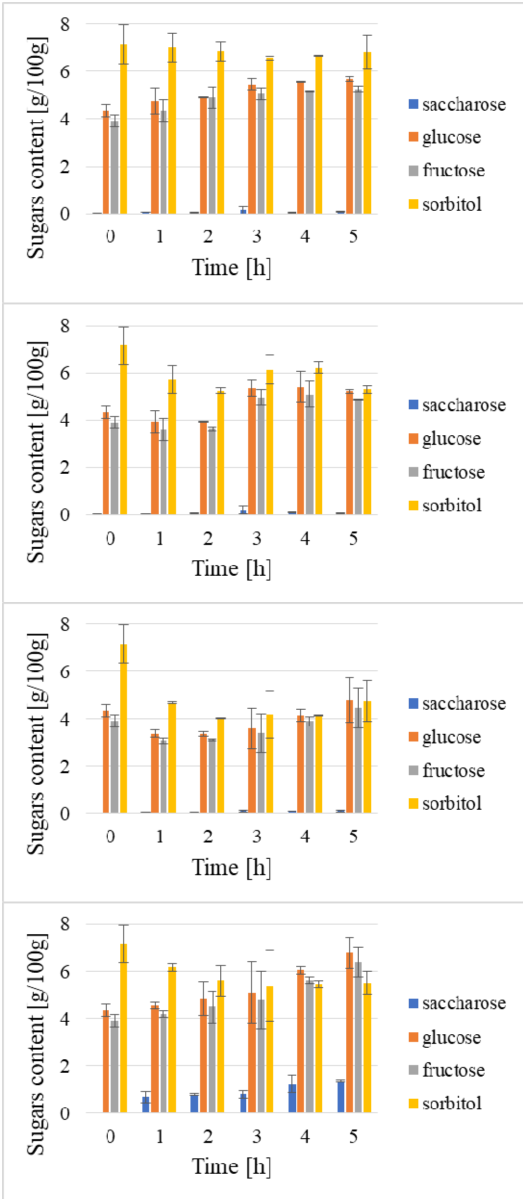

Figure 5. Changes in the content of individual sugars and polyol in chokeberry, depending on the dehydration time at different temperatures, with the use of sucrose solution

Figure 6 shows the loss of water in chokeberry fruit. The greatest losses (even 1 gH_2O/g i.d.m.) were recorded at 55°C, and the lowest at 25°C (up to 0.3 gH_2O/g i.d.m.). The most intensive water migration always occurred in the first hour of the process.

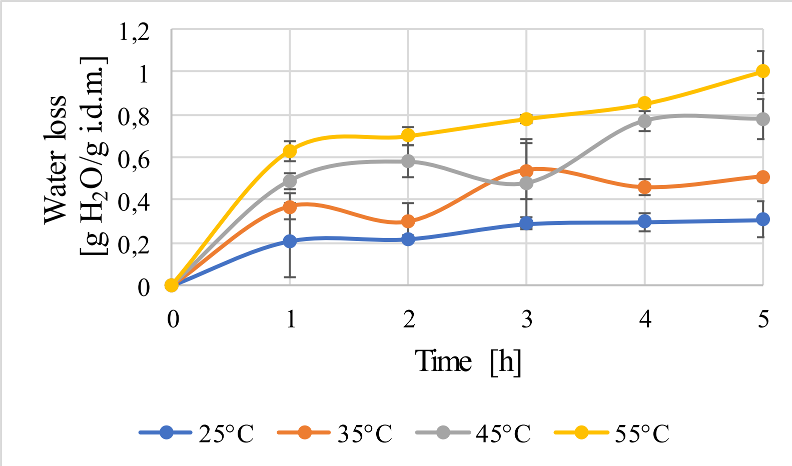

Figure 6. Water loss in chokeberry dehydrated in sucrose solution at different temperatures

In the case of solids gain (Figure 7), a certain fluctuation was noted, but no clear relationship was observed between the temperature and the amount of its increase. In general, the values were low, below 0.14 g/g i.d.m., and similar to those obtained for frozen blueberries and gooseberries [22, 23].

The advantage of water migration from the tissue over the penetration of the osmotic substance into the tissue is characteristic of many raw materials subjected to osmoconcentration (both fruits and vegetables) with the use of various osmotic factors, such as sucrose, salts, concentrated fruit juices [4, 10]. The process temperature plays an important role in mass transport during dewatering. Water loss in chokeberry (dehydrated in a 50% sucrose solution) increased (from 29.13 to 36.01%) after applying a higher temperature (from 50 to 70°C), similar results were obtained when dehydrating chokeberry in cherry juice, concentrated apple juice and inulin [8].

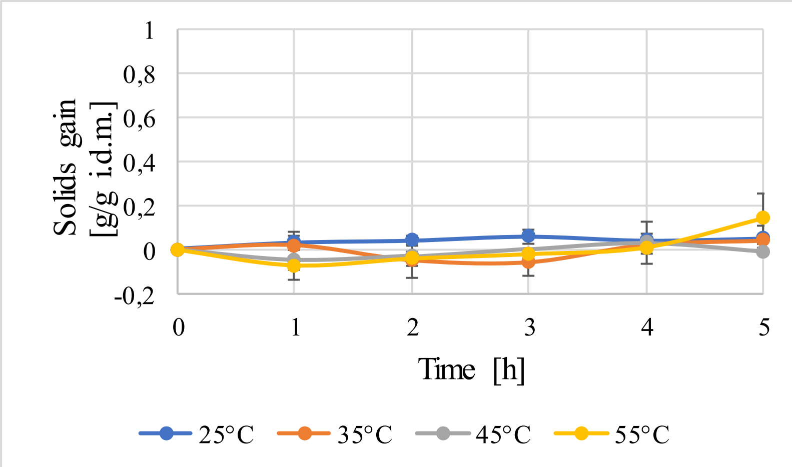

Figure 7. Solids gain in chokeberry dehydrated in sucrose solution at different temperatures

Different saccharide composition of fruit and the presence of sorbitol affect the energy value of the products. Dehydration in sucrose increases this value. The greatest increase (Figure 8) was recorded for apricots processed at 55°C (energy value of sugars and polyol – max. 545 kJ/100g of dehydrated fruit; assuming energy values to be 17 kJ/g for sucrose, glucose and fructose, and 12 kJ/g for sorbitol). In general, the effect of increasing the caloric value should be minimized. Chokeberry dehydrated in the same conditions as apricots contained sugars with about twice lower energy value. By dehydrating plums and apples in a sucrose solution, Klewicki and Uczciwek [13] obtained energy values at the level of 500-600 kJ/100 g (depending on temperature), which is comparable to apricot dehydrated for 4÷5 hours in the presented research.

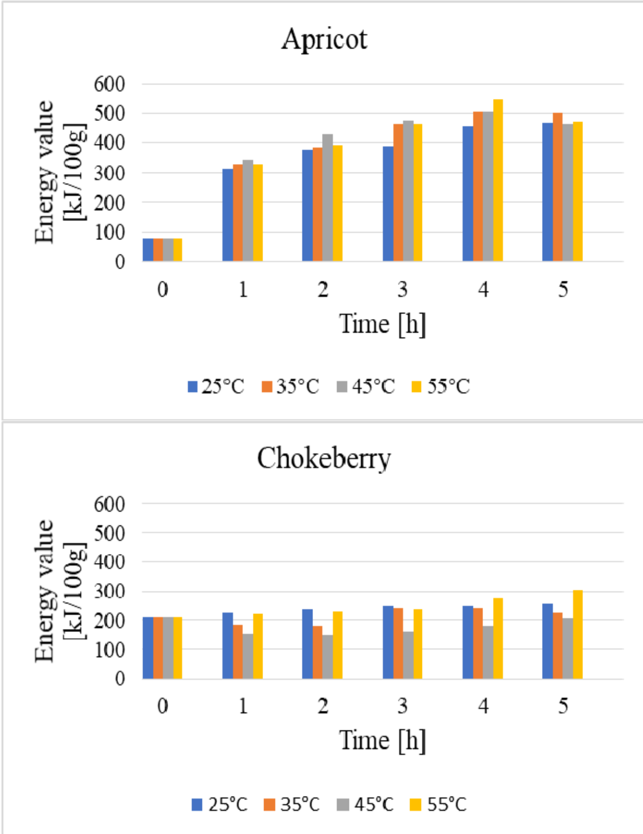

Figure 8. The energy value of the sum of sugars and sorbitol contained in fruit dehydrated under various conditions

Conclusions

The rate of increase of the dry substance level depends significantly on the material to be dehydrated. In the case of apricot, after the first hour of dehydration, the dry matter content increased approximately threefold, while in chokeberry the increase was only 8÷19%, depending on the temperature.

The use of the temperature of 55°C increases the content of glucose and fructose in apricot, with a simultaneous decrease in the proportion of sucrose, which is a consequence of its hydrolysis. The process carried out at 25÷35°C leads to the opposite results.

Chokeberry is not very susceptible to migration of sucrose at temperatures up to 55°C; there is no visible relationship between the temperature and solids gain. The transport of water is greater; most intense at 55°C – 1 g H_2O/g i.d.m. after five hours. The water loss in apricots is greater than in chokeberry (4.68 g H_2O/g i.d.m. after five hours).

At 25°C, after the first hour of dehydration, the energy value of chokeberry saccharides was 315 kJ/100g. Chokeberry was characterized by about two times lower energy value than apricot dehydrated under the same conditions.

Acknowledgements

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