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Research of vacuum drying peculiarities of wild berries

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ABSTRACT

Vacuum drying is a promising way of preserving plant raw materials, including fruits and berries. To improve the efficiency of this technology it is necessary to choose appropriate dehydration parameters. The purpose of this work was to study the processes of vacuum drying of wild-growing berries under different conditions. As objects of research, it was taken a strawberry, red currant, blackberry and raspberry. The experiments were carried out at different values of temperature, residual pressure, and heat flow rate. It is established that temperature increase in the chamber reduces the duration of moisture removal and at the same time, it worsens the quality characteristics of the dried berries. The most effective drying temperature is 50°C. It is found that an increase of the residual pressure prolongs the duration of vacuum drying. The effective value of the residual pressure is 4.5 ± 0.5 kPa for blackberry and strawberry and 6.5 ± 0.5 kPa for red currant and raspberry. The increase in the heat flow rate on one side leads to a reduction in the time for the product heating to the desired temperature, on the other hand, reduces the quality of dried berries due to the high heating rate at the initial stage of drying. At vacuum drying of raspberry, the effective heat flow rate is 3.5 ± 0.3 kW m-2, for red currant and blackberry drying this value is 5.0 ± 0.3 kW m-2 and for blackberry - 6.5 ± 0.3 kW m-2.The value of water activity in berries with different moisture content is analyzed. In fresh wild berries, water activity is 0.96-0.98. After vacuum drying, water activity in berries decreases to 0.15–0.18.

Keywords: *berries, vacuum drying, technological modes*.

1. INTRODUCTION

Providing the population with safe food of high quality is one of the important tasks of our country. Unfortunately, in recent decades there has been a significant deterioration in the environmental situation in several regions of the country, and as a result food is contaminated with pesticides, radionuclides, toxic metals (lead, zinc, mercury, copper, arsenic, cadmium), various nitro compounds (nitrites, nitrates, etc.), antibiotics, etc.

The existing ecological situation adversely affects the health of the population. The resulting consequences include an increase in morbidity, increased number of neonatal pathology cases and a decrease in life expectancy. One of the stand-alone problems is vitamin deficiency, according to the Institute of Nutrition of the Russian Academy of Medical Sciences, a deficiency of vitamin C is observed in 80–90% of Russia's population, 60% population has lack of vitamin A, B1, B2, B6, and a mineral deficiency is also revealed [3].

It is possible to withstand the adverse effects of environmental factors with a help of proper nutrition, implying that the human body gets with the food the desired set of nutritional ingredients, balanced by the ratio and quantity [21, 22, 24]. Thus, there is a need to develop products enriched with various biologically active substances, as well as to expand the possibilities of consuming foods with high biological value [20]. One of these products is berries, which play an important role in the human diet [28, 29, 30, 31, 39, 40, 41].

The biological value of berries is not so much in its energy value as in the high content of various kinds of micronutrients: mineral and pectin substances, vitamins, essential amino acids, etc. [2, 11]. However, due to the climatic characteristics of most regions of our country, the use of berries in food is seasonal. In this regard, there is a need for conservation of this product with the possibility of maximum preservation of biologically active components of this raw material. Preservation of berry raw materials makes it possible to smooth seasonal production of this product and ensure its uniform consumption throughout the year.

Among all the preservation methods, drying is one of the most effective ways. Its advantages include a small mass of the dried product, inexpensive packaging, the possibility of a substantial extension of storage and transportation times without the use of cold, etc. [16, 17].

Currently, the most promising way to dehydration is vacuum drying, which is performed at a pressure below atmospheric, but above the triple point of water [5, 32, 33, 34]. Due to the creation of a vacuum in the chamber, it is possible to lower the boiling point of moisture in the product and carry out the process at a relatively low temperature [4, 12, 6, 15, 18, 37, 38]. Products obtained by the vacuum drying method are characterized by a rather small degree of shrinkage, high dehydration indexes and long shelf life, which is especially important in the processing of berry raw materials [7, 8, 14, 19, 26, 27, 35, 36].

Dry berries produced by the method of vacuum dehydration can find wide application in the dairy industry in the production of all kinds of yogurt, cheese, fruit milk, cream, etc. In cooking they can be used in kissels, sauces, fillings, gravies, etc. [9, 10] As far as the confectionery industry is concerned, berries can be used in waffle production as flavours, dyes and fat stabilizers, as well as for marmalade production [1]. Berry powders are raw materials for the production of children's and dietary food; they are used in public and individual nutrition, as well as in the production of functional foods, flavored tea [42, 43, 44].

Thus, the purpose of this work was to study the processes of vacuum drying of wild-growing berries under different conditions.

2. EXPERIMENTAL SECTION

Studies were conducted in Russia, Kemerovo, at the Kemerovo State Institute of Food Science and Technology in 2015-2017.Objects of research were strawberry, red currant, blackberry,and raspberry. For the drying process, an installation was used, the scheme of which is shown in Figure 1.

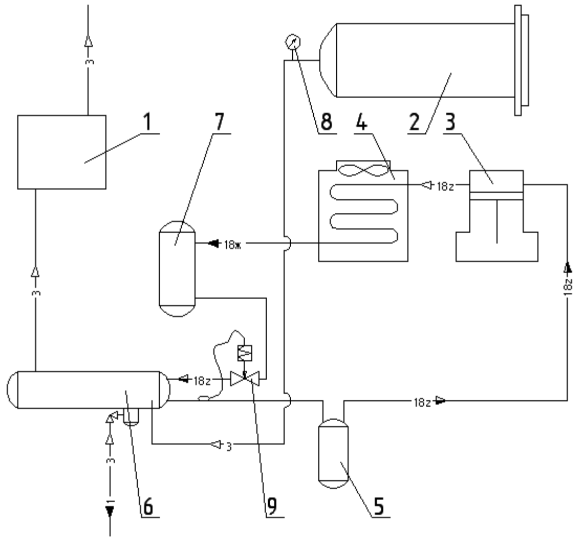

Fig. 1. Scheme of an experimental vacuum drying installation: 1 – vacuum pump, 2 – working chamber, 3 – compressor, 4 – capacitor, 5 – liquid separator, 6 – desublimator, 7 – receiver, 8 – vacuum gauge, 9 – thermostatic expansion valve.

The experimental installation includes a drying chamber 2, where a product is loaded into a pallet mounted on a weight sensor. In addition, the chamber has two infrared lamps, as well as temperature and pressure sensors. The air from the chamber is got out by a vacuum pump 1. The air passes through the desublimator 6; the moisture from the air is frozen on the evaporator of the refrigerating machine. This is necessary to reduce the load on the vacuum pump. The refrigeration unit consists of a compressor 3, an air capacitor 4, a liquid separator 5, a receiver 7, an evaporator and a thermostatic valve 9.

The installation works in the following way. The test sample is loaded into a drying chamber, which is hermetically sealed with a lid. Further, a vacuum pump is introduced to lower the pressure in the chamber. When the set residual pressure is set in the chamber, infrared heating lamps are turned on and vacuum drying begins. The chamber is equipped with temperature, mass and pressure sensors, which allow controlling the process of moisture removal. Signals from the sensors through the converter come to the computer, where the data are continuously registered.
An installation shown in Figure 2 was used, to determine the activity of water.

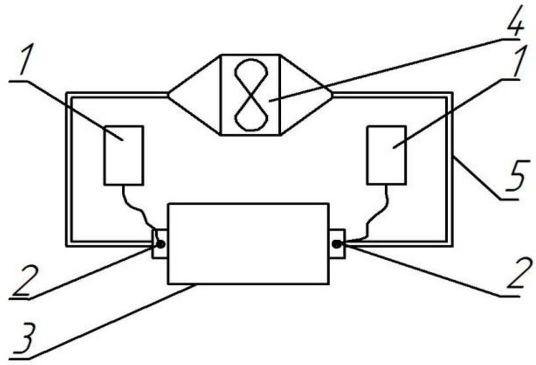

Fig. 2. Scheme of the installation for the determination of water activity: 1 – meters of temperature and relative humidity, 2 – sensors for meters of temperature and relative humidity, 3 – working chamber, 4 – ventilator, 5 – silicone hose.

All elements of the installation are connected by a silicone hose 5, forming a sealed circuit. For the organization of forced air movement in this circuit, a ventilator 4 is provided. The sensors of the temperature and relative humidity meters 2 are installed at the input and output of the working chamber 3. The air in the system is pre-dried by an adsorbent located in the lower part of the working chamber 3. Then the space between the adsorbent and air is separated by a shutter and the analyzed product is placed in the working chamber 3. Next, the ventilator 4 is turned on and the air, moving along a closed circuit, contacts the product surface and is saturated with moisture evaporating from its surface. The experiment is terminated when an equilibrium state is reached - that is, when the indications of meters 1 show the same value. According to these indicators, water activity is determined.
The organoleptic evaluation was performed in accordance with the method presented in Table 1 [3]. At the same time, such indicators as taste and smell, consistency and color were evaluated. The maximum score was 40 points.

Table 1. Method of organoleptic evaluation of dry berries

Parameters	Evaluation	Relief
Smell	15-point scale	
Well-defined	15-12	0-3
Weak	11-6	4-9
Stale	7-4	8-11
Musty	3-0	12-15
Consistency	15-point scale	
Homogeneous	15-12	0-3
Berries of different degree of dryness	11-6	4-9
Presence of stuck mass	7-4	8-11
Presence of decortice	3-0	12-15
Colour	10-point scale	
Uniform	10-6	0-4
Uneven	5-0	5-10

The moisture content in the berries was determined by the short-course method with a help of the IEMF device, by drying the sample of the product according to GOST 3626-73 and according to GOST R 51464-99.

The experiments were set three times to obtain more reliable results.

3. RESULTS SECTION

Firstly, they haveconducted experiments on the selection of the drying temperature of the berries. In this series of experiments, the residual pressure was 4.5 ± 0.5 kPa, the heat flow rate was 5.0 ± 0.3 kW m^{-2}. The temperature in the chamber was set at the following values: 40, 50 and 60 °C. Drying at a higher temperature is not expedient due to the significant influence of high temperatures on the biologically active components of the product. During the experiments, the change in the mass of the product and the temperature in the product and in the chamber was recorded.

Figure 3 shows the graphs of the change in the relative mass of red currant in the process of vacuum drying at different heating temperatures.

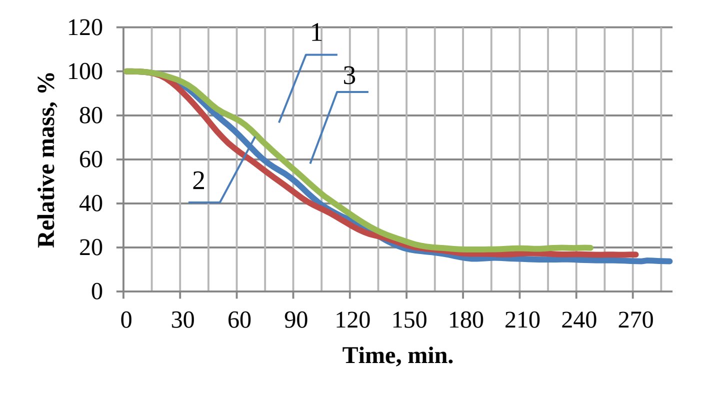

Fig. 3. Diagram of the change in the relative mass of current at chamber temperatures: 1 – 60°C, 2 – 50°C and 3 – 40°C.

During the first 15 minutes, the dryer installation goes into operating mode. First of all, the chiller and the vacuum pump are started, which reduces the pressure in the working chamber from the atmospheric to the set value - in this case, 4.5 ± 0.5 kPa. Infrared lamps are turned off. At the first stage, moisture is removed in the macro capillaries of the product. In this drying period, the relative weight of the berries varies insignificantly - from 100% to 95-97%. By reducing the pressure in the working chamber, the temperature on the surface of the berries drops sharply by 10 degrees on average. The duration of the first drying phase is about 15-20 minutes.

Then the infrared lamps are switched on and the second stage begins, during which a constant rate of moisture removal is observed. At this stage, the main part of moisture in the product - osmotically - bound moisture and moisture in the microcapillaries - is removed.

In experiments with the chamber temperature of 60°C, the second stage was completed 125±10 minutes later after the start of the drying process. By this time, the relative mass of red currant was 36±2 % of the initial value. In this mode, the temperature on the surface of the product reaches 60°C in 60 minutes after the start of drying. The thickness of the berries,in this case, is heated only in 100±10 minutes after the start of drying. Thus, the duration of the second period was 95±10 minutes.

In the case where the temperature in the chamber was 50°C, the rate of moisture removal began to decrease after 135±10 min. from the beginning of the drying process. After the second stage, the relative mass of red currant was 28±2%. The temperature on the surface of the berry reached 50 °C in 50±5 minutes and the temperature in the thick mass - in 90±10 minutes, after the beginning of the drying process. The duration of the second stage of vacuum drying was 115±10 minutes.

When the temperature in the chamber was set at 40°C, the second stage was completed in 150±10 minutes after the start of the drying process. Relative mass by that time was 22% of the initial value. The temperature on the surface of the berries reached the set value in 54±5minutes after the start of the drying process.

At the third stage, the moisture of mono and polymolecular adsorption is removed. This type of connection is the most durable and in the drying process is removed very slowly. At temperatures in the chamber of 40, 50 and 60 °C, the duration of the third stage was 77±10, 95±10 and 123±10min. By the end of the drying process, the relative weight of dry berries was 18±1%, 17±1%,and 14±1%, respectively.

The reliability of the scheme approximation is presented in Fig. 3 is 0.998.

Table 2 shows the duration of vacuum drying and the moisture content of all berries.

Table 2. Indices of vacuum drying of wild berries in temperature.

Berries	Temperature in the chamber, °C		
	40	50	60
Duration of the drying process, min			
Strawberry	265±10	230±10	190±10
Red currant	270±10	230±10	200±10
Blackberry	265±10	240±10	190±10
Raspberry	275±10	235±10	195±10
Moisture content in dry berries, %			
Strawberry	7.3±0,2	5,8±0,2	4,3±0,2
Red currant	8,9±0,2	6,5±0,2	4,5±0,2
Blackberry	8,1±0,2	6,2±0,2	4,4±0,2
Raspberry	7,8±0,2	6,4±0,2	4,5±0,2

To analyze the effect of temperature on the quality of the product, an organoleptic evaluation of dried berries was conducted. The results of this evaluation are presented in Table 3.

Such factors as the duration of dehydration, the moisture content of the dry product and the organoleptic evaluation were taken into account while the determining of the effective drying temperature of berries. On the one hand, an increase in the heating temperature leads to a shortening of the duration of the vacuum drying, on the other hand, to quality deterioration of the finished product. According to the results of experimental studies, it can be concluded that the effective drying temperature is 50°C. The drying time under this regime is 230–240 min, and the organoleptic score is 33–34 points out of 40. At a higher temperature, there is a significant deterioration in the quality of the product, and at a lower temperature – an increase in the duration of dehydration.

Table 3. Results of organoleptic evaluation of dry berries in temperature selection, points

Parameters	Temperature in the chamber, °C		
	40	50	60
Strawberry			
Taste and smell	14±1	13±1	11±1
Consistency	13±1	12±1	9±1
Colour	9±1	8±1	7±1
Total	36±3	33±3	27±3
Red currant			
Taste and smell	14±1	13±1	12±1
Consistency	13±1	13±1	11±1
Colour	9±1	8±1	8±1
Total	36±3	34±3	31±3
Blackberry			
Taste and smell	13±1	13±1	11±1
Consistency	13±1	12±1	12±1
Colour	9±1	8±1	7±1
Total	35±3	33±3	30±3
Raspberry			
Taste and smell	13±1	13±1	11±1
Consistency	14±1	12±1	9±1
Colour	9±1	9±1	8±1
Total	36±3	34±3	28±3

Further experiments were carried out to select the residual pressure in the chamber. The experiments were carried out at 4.5 ± 0.5 kPa; 6.5 ± 0.5 kPa and 8.5 ± 0.5 kPa. The drying temperature was 50°C; the heat flow rate was 5.0 ± 0.3 kW m^{-2}.

Figure 4 presents the diagrams of the relative mass dependence on the duration of the vacuum drying of the blackberry during the selection of the residual pressure in the chamber.

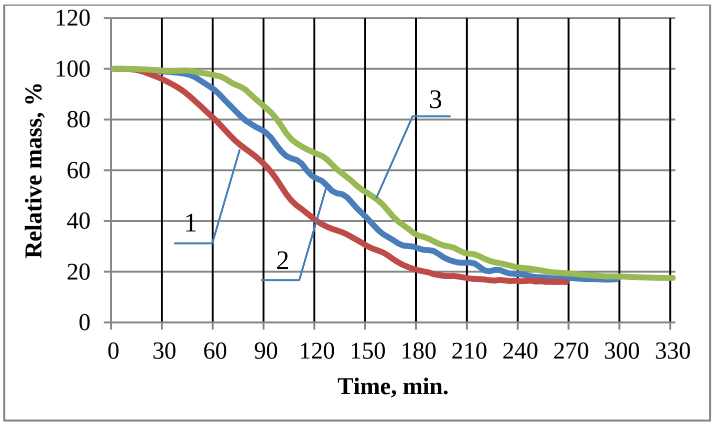

Fig. 4. Diagram of the dependence of the relative mass on the duration of the vacuum drying of the blackberry at the residual pressure in the chamber: 1 - 4.5 ± 0.5 kPa; 2 - 6.5 ± 0.5 kPa; 3 - 8.5 ± 0.5 kPa.

It was found that the increase of the residual pressure reduces the intensity of moisture removal. In 30 minutes later after the start of the drying process, when the installation went into operation, the relative weight of the blackberry at a residual pressure of 4.5 ± 0.5 kPa was 95.6±0,5%, and at a residual pressure of 6.5 ± 0.5 kPa and 8.5 ± 0.5 kPa, was 98.5±0,5% and 98.9±0,5%, respectively. At a residual pressure of 4.5 ± 0.5 kPa, the period of constant drying rate occurs after 40±5 minutes, while at a residual pressure of 6.5 ± 0.5 and 8.5 ± 0.5 kPa – after 60±5 and 80±5 min, respectively. The duration of the second stage of vacuum drying at all values of the residual pressure is approximately the same and amounts to 110–120 minutes. The duration of the third stage at a residual pressure of 4.5 ± 0.5 kPa was about 80±5 minutes. By the end of this stage, the relative weight of the dried blackberry was 16±1% of the initial value. When the residual pressure was 6.5 ± 0.5 kPa, the duration of the third stage was 125±10 minutes and the relative weight of the product at the end of drying was 17.2±0,5%. At a residual pressure of 8.5 ± 0.5, a similar duration of the third stage is observed (134±10 min). The relative weight of the dried blackberry at the same time was 17.6±0,5%.

The reliability of the scheme approximation is presented in Fig. 4 is 0.992.

To select the effective value of the residual pressure, an organoleptic evaluation of dry berries was also conducted. Table 4 presents data on drying time, organoleptic evaluation,and specific energy consumption.

Table 4. Efficiency parameters of vacuum drying of wild berries at different residual pressure.

Berry	Residual pressure, kPa		
	4.5±0,5	6,5±0,5	8,5±0,5
Drying time, min			
Strawberry	230±10	310±10	340±10
Red currant	230±10	280±10	310±10
Blackberry	240±10	300±10	330±10
Raspberry	235±10	270±10	305±10
Organoleptic evaluation, points			
Strawberry	33±3	34±3	33±3
Red currant	34±3	36±3	35±3
Blackberry	33±3	35±3	35±3
Raspberry	34±3	36±3	34±3
Specific energy consumption, kW kg^{-1} of moisture			
Strawberry	4,4±0,1	4,2±0,1	5,3±0,1
Red currant	4,1±0,1	4,5±0,1	5,4±0,1
Blackberry	3,9±0,1	4,4±0,1	4,9±0,1
Raspberry	5,4±0,1	5,9±0,1	6,1±0,1

According to the results of the research, it is possible to recommend vacuum drying of blackberry at a residual pressure in the chamber of 4.5 ± 0.5 kPa. When the residual pressure rises to 6.5 ± 0.5 kPa, the duration of dehydration increases by 60 minutes, and the organoleptic score increases by 2 points. At the same time, specific energy consumption also increases from 3.9±0,1 to 4.4±0,1 kW kg^{-1} of moisture. A further increase in the residual pressure in the drying chamber leads only to an increase in the duration of the process and a decrease in the quality of dry blackberry and an increase in the specific energy consumption.

Effective drying of red currant takes place at a residual pressure in the chamber of 6.5 ± 0.5 kPa, which is due to a higher organoleptic evaluation in comparison with other regimes. In addition, the specific energy consumption at a residual pressure of 6.5 ± 0.5 kPa for red currant is lower than at a residual pressure of 4.5 ± 0.5 kPa and amount to 4.5±0,1 kW kg^{-1} of moisture. Raspberry is also effectively dried at a residual pressure of 6.5 ± 0.5 kPa comparing to drying at a residual pressure of 4.5 ± 0.5 kPa, when the organoleptic score increases by 2 points and the drying time increases by only 35±5 minutes. Increasing the residual pressure for both red currant and raspberry does not entail a significant improvement in the quality of the dried berries. For strawberry, the effective residual pressure in the chamber is 4.5 ± 0.5 kPa, as the increase in the residual pressure to 6.5 ± 0.5 kPa, the qualitative estimate rises by 1 point, and the drying time increases by 80±5 min. Further increase in residual pressure does not lead to an improvement in the quality of dry strawberry.

Further, the heat flow rate was selected. The experiments were carried out at the previously selected temperature and the residual pressure in the chamber. The heat flow rate in different experiments was 2.0; 3.5; 5.0; 7.5 and 9.0 kW m^{-2}.

Figure 5 shows the duration of vacuum drying of berries, organoleptic evaluation, the mass fraction of moisture and specific energy consumption for different heat flow rate.

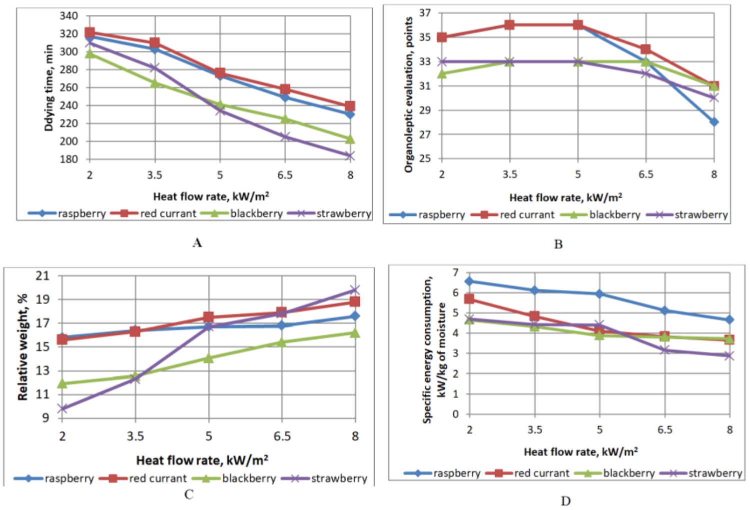

Fig. 5. Diagrams of the duration of vacuum drying of berries (A), organoleptic evaluation (B), the relative weight of the dry product (in) (C) and the specific energy consumption (D) from the heat flow rate.

The increase in the heat flow rate on one side causes a reduction in the duration of the warming of the berry to the desired temperature, but on the other hand, an excessively high heating rate provoke a crust formation on the surface of the product that prevents further migration of moisture from the inner layers to the periphery. With a heat flow rate of more than 5–6.5 kW m^{-2}, the quality of dry berries is reduced. It was also found that the lower the heat flow rate is, the slower the heating of the product and the deeper moisture removal is observed, which is evident from Figure 5C. However, in this case, the specific energy consumption increases, because the drying time is increased. Basing on this data, we can conclude that it is advisable to perform a vacuum-drying of raspberry, red currant and strawberry at a heat flow rate of 5.0 ± 0.3 kW m^{-2}. As for the blackberry, the effective value of the heat flow rate is 6.5 ± 0.3 kW m^{-2}.

At the final stage of the research, an analysis was made of the changes in water activity in wild berries during the drying process. Water activity is one of the most important characteristics used in the field of food preservation [13]. This parameter characterizes the state of moisture contained in the product and is numerically equal to the ratio of the vapor pressure of water above this product to the vapor pressure over pure water at the same temperature. Information on the magnitude of water activity is necessary to take into account factors such as the growth of microorganisms and biochemical reactions that lead to product spoilage.

Figure 6 shows the water activity of wild berries with a different mass fraction of moisture in them.

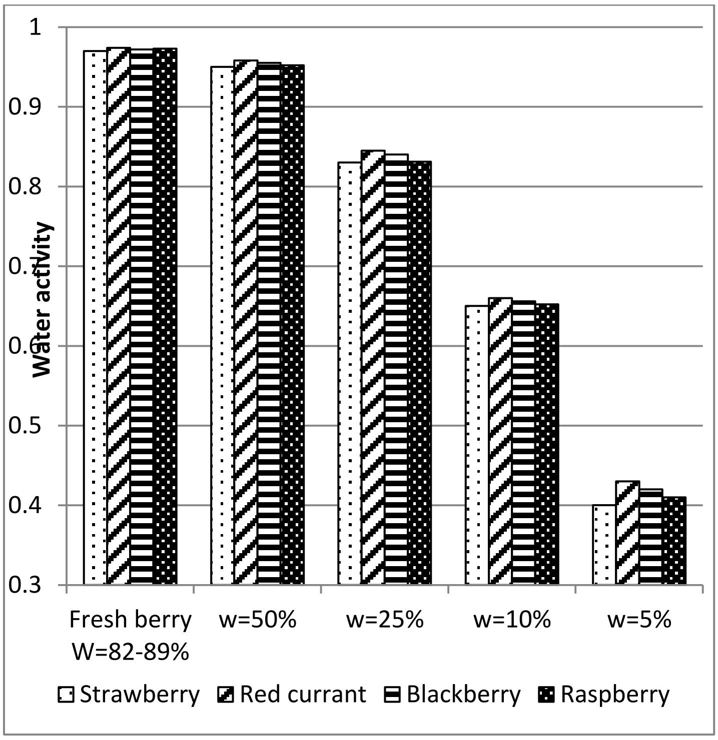

Fig. 6. Water activity of wild berries.

Fresh berries are characterized by a relatively high water activity index, which is about 0.97±0,02. As the moisture is removed, the water activity decreases in a non-linear way, and when the moisture content in berries reaches 5%, the water activity decreases to 0.40–0.43. Differences between water activity in different berries with the same moisture content are insignificant. The relatively low value of water activity in dehydrated berries causes a significant decrease in the activity of microorganisms.

4. CONCLUSIONS

The carried out studies allowed making the following conclusions:

1. The effective temperature of the vacuum drying of berries is 50°C.
2. The effective value of the residual pressure is 4.5 ± 0.5 kPa for blackberry and strawberry and 6.5 ± 0.5 kPa for red currant and raspberry.
3. The effective value of the heat flow rate for raspberry, red currant,and strawberry berries is 5.0 ± 0.3 kW m^{-2}. As for the blackberry, the effective value of the heat flow rate is 6.5 ± 0.3 kW m^{-2}.
4. The water activity was analyzed in berries with a different mass fraction of moisture. It was found that in dry berries the activity of water is about 0.4, which is significantly lower than the threshold value of development of the majority of microorganisms leading to product spoilage.

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