Production of components for special-purpose products at continuous freeze drying of plants

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Abstract. Experimental studies on freeze-drying of juices and fermented milk drinks at continuous plants were carried out. High-quality components comparable with raw materials for the production of special-purpose products are obtained.

1. Introduction

The main cause of micronutrient deficiency in the body of a modern human both in Russia and in all economically developed countries is a sharp decrease in energy consumption and a corresponding reduction in the need for food as an energy source, which does not allow providing evolutionary physiological needs of a body in a number of essential nutrients due to adequate caloric intake consisting of conventional foods. An effective way to eliminate micronutrient deficiencies is the large-scale production of special-purpose foods that have a positive effect on physiological functions and metabolism in General, as well as having a certain psychotherapeutic effect. Among the food products that have protective functions, biologically active dairy products, fruits, berries, vegetables, and their juices are of paramount importance. According to the world health organization, the content is 700-800 g of fruits and vegetables in the daily diet will help reduce the risk of cancer, cardiovascular and some age-related diseases by almost 50 %. However the pronounced seasonality of agricultural production, limited shelf life of food products, the complexity of preserving high biological properties without special equipment do not allow them being used throughout a year. The remove of moisture from the raw material by drying to a moisture content of 3.6-4.5 % will make it possible to store it in normal conditions for a long time.

2. Literature review

2.1. Legislative framework

The government of the Russian Federation adopted the "Federal scientific and technical program for the development of agriculture for 2017-2025", developed taking into account the doctrine of food security of the Russian Federation, approved by the decree of the President of the Russian Federation dated January 30, 2010 No. 120 "on approval of the Doctrine of food security of the Russian Federation", and the Strategy of scientific and technological development of the Russian Federation, approved by the decree of the President of the Russian Federation dated December 1, 2016 No. 642 "on the Strategy of scientific and technological development of the Russian Federation" [2].
2.2. Analysis of experimental and theoretical works on the intensification of freeze-drying process

A great contribution to the development of the energy components of the intensification of drying with combined energy supply was made by A. Lykov, A Ginzburg, P Lebedev and V Karpov, D Lebedev, M Zhukovsky, etc. [1-5, 8]. V Kasatkin and N Kasatkina significantly developed the theory of freeze drying [6, 7]. They theoretically substantiated the hypothesis of combined energy supply for freeze-drying of liquid thermolabile food products in continuous operation:

- In the field of low vacuum, there is no fundamental obstacle to create a directional movement of the vapor-gas medium, the necessary energy power to remove the freeze-dried moisture;
- Acting directly on the water molecules, microwave energy is more efficient in the early stages of drying, and the power of the microwave generator uniquely determines the duration of drying;
- The effect of ultrasound leads to turbulence, disruption of the boundary layer, as well as to the periodic creation of a vacuum in the phase of vacuum of the sound wave, which leads to an acceleration of the process at the drying stage.

It is efficiently distributed over the volume of the drying additional types of energy the wave nature, thereby reducing the power consumption of the process compared to the traditional convective-vacuum 3.5 - 4.5-fold (combined energy supply, combining form of energy, stages of its use and the spatial distribution), he developed a mathematical apparatus for calculating the modes of technological processes for a given quality indicators of the finished product and determining the parameters of the equipment to achieve a given performance and installation of the type of ICF-D-CE-L (installation of continuous freeze drying with combined energy supply for liquid thermolabile products).

3. Research methodology

On the basis of theoretical studies of the kinetics of continuous freeze drying in a single vacuum cycle of liquid thermolabile food products, three stages of the technological process of dehydration are established:

- Evaporative self-freezing of liquid thermolabile food products in cryogranulated by spraying in vacuum and in the field of IR radiation.
- Freeze-drying of free moisture from cryopreserving juice in the fields of ultrasound, microwave energy and forced gas flow.
- Drying of residual moisture in the ultrasound field and in the forced gas flow at low pressure and positive temperatures.

Developed and manufactured a prototype installation of continuous action for freeze drying of liquid thermolabile food products with a capacity of evaporated moisture 1 kg/h (ICF-D-CE-L-01), equipped with a control system that allows to implement the technology of obtaining lyophilized concentrates (humidity 3.5-4.5 %).

3.1. Description of the ICF-D-CE-L-01 installation

Figure 1 shows the schematic diagram of the installation of freeze drying for dehydration of thermolabile products in the fields of ultrasound and microwave and forced flow of inert gas, which received a patent and a positive decision to grant a patent for the invention [2]. The unit consists of a cylindrical drying chamber with microwave (16) and ultrasound (4) sources. In the upper part of the drying chamber there is a spray chamber, on the cover of which the IR emitter (2) is fixed. The chamber has its own desublimator (3) as well as a valve connected to the vacuum pump (12). In the lower part, the chamber is connected to the discharge screw (8) via a vacuum seal (15). The fermented milk product is fed by a dosing feeder (pump) (10) from the tank (14) and sprayed through an ultrasonic nozzle (1) in the spray chamber. The product feed mode is controlled by the spray control unit (DCS). Drops of the product during the flight are cooled and frozen due to intensive evaporation of moisture in a vacuum. The droplets are exposed to the radiation energy of the IR emitter (2). Further drops with the dried top layer flow down-into the drying chamber. Drying agent (inert gas, air) at the stage of removal of residual moisture is fed to the bottom of the drying chamber through a thermostat (13) pump (11) in the diffuser (5). In order to control the operating modes, the unit is equipped with:
- Temperature – a harness, introduced to the drying column with seven thermocouples (TP₀, TP₁₀₀, TP₂₀₀, TP₃₀₀, TP₄₀₀, TP₅₀₀, TP₆₀₀) arranged sequentially at intervals of 100 mm starting from the bottom of the column with the zero mark and finishing in the top 600 mm of the Thermocouple are connected to sublake control heating system.
- Pressure - 3 sensors PMT 6 (P₀, P₃₀₀, P₆₀₀), which are connected to the converters 13VT3-003 and sub-unit control unit vacuum.
- Humidity - nylon "stocking" is omitted in the column for drying of sample of the dried granulated juice. The post granulated juice, taken in a nylon "stocking", cut every 100 mm at 0, 100, 200, 300, 400, 500, 600, corresponding to the setting level thermocouple TP₀, TP₁₀₀, TP₂₀₀, TP₃₀₀, TP₄₀₀, TP₅₀₀, TP₆₀₀ and determined the moisture content according to GOST 15113.4-77 to the corresponding points W₀, W₁₀₀, W₂₀₀, it’s a W₃₀₀, W₄₀₀, W₅₀₀ laptop, W₆₀₀.

![Figure 1. Schematic diagram of a continuous laboratory installation for freeze drying of liquid thermolabile food products.](image)

3.2. Principle of operation

After the formation of a vacuum in the sputtering chamber includes capacitors (Desublimers) (3) and IR emitters (2) and through the nozzle (1) is fed product (yogurt). Cryogenservice drops of yogurt start in the field of infrared radiation at a temperature of Desublimers –35°C refrigeration machine support (6). At the same time, the drying agent (inert gas, air) is fed, heated to a temperature of +20...+40 °C. The amount of the supplied agent is adjusted so that the pressure in the chamber controlled by the sensor (7) at the level of m₀ does not rise above 100 PA. When the product in the drying chamber level m₀ is switched on ultrasound, at the level of m₃ turns on the microwave, and when it reaches the level marker m₆₀₀ (upper level) shall be enforced by the auger actuator (9) and starts unloading freeze-dried product. The drying process is continuous under the influence of ultrasound and microwave energy in the forced flow of inert gas. The level of riograndense dried in the drying chamber is maintained by management at around m₆₀₀.
4. The results of experimental studies

Experimental studies were carried out on the ICF-D-CE-L-01 installation.

4.1. Kinetics of drying

The drying results of sea-buckthorn and black-fruit-Rowan juices are presented in Tables 1-2 (without ultrasound).

Table 1. Drying Kinetics of sea buckthorn juice without IR heaters during spraying at a gas temperature of 40°C.

| Height H, mm | 0   | 100 | 200 | 300 | 400 | 500 | 600 |
|-------------|-----|-----|-----|-----|-----|-----|-----|
| Experiment  |     |     |     |     |     |     |     |
| W %         |     |     |     |     |     |     |     |
| T, °C        |     |     |     |     |     |     |     |
| P, Pa        |     |     |     |     |     |     |     |
| 1            | 3.6 | 4.1 | 4.8 | 6.0 | 10.3| 42.8| 77.0|
| 2            | 3.6 | 4.3 | 5.1 | 6.6 | 11.1| 44.2| 79.0|
| 3            | 3.6 | 4.2 | 4.9 | 6.3 | 10.5| 43.3| 78.3|

Table 2. Drying Kinetics of sea buckthorn juice with IR heaters during spraying at a gas temperature of 20°C.

| Height H, mm | 0   | 100 | 200 | 300 | 400 | 500 | 600 |
|-------------|-----|-----|-----|-----|-----|-----|-----|
| Experiment  |     |     |     |     |     |     |     |
| W %         |     |     |     |     |     |     |     |
| T, °C        |     |     |     |     |     |     |     |
| P, Pa        |     |     |     |     |     |     |     |
| 1            | 3.6 | 4.1 | 5.1 | 5.9 | 9.1 | 42.1| 73.0|
| 2            | 3.6 | 4.1 | 5.0 | 6.3 | 9.0 | 41.8| 72.4|
| 3            | 3.6 | 4.1 | 5.0 | 6.0 | 9.3 | 41.5| 71.2|

The results of drying fermented milk drinks enriched with two cultures bifidus bacteria and lactobacilli are presented in Tables 3-4 (conducted with ultrasound).

Table 3. Kinetics of drying fermented milk product without IR heaters during spraying at a temperature of 40°C.

| Height H, mm | 0   | 100 | 200 | 300 | 400 | 500 | 600 |
|-------------|-----|-----|-----|-----|-----|-----|-----|
| Experiment  |     |     |     |     |     |     |     |
| W %         |     |     |     |     |     |     |     |
| T, °C        |     |     |     |     |     |     |     |
| P, Pa        |     |     |     |     |     |     |     |
| 1            | 3.7 | 3.8 | 4.1 | 6.3 | 27.0| 60.2| 86.1|
| 2            | 3.7 | 3.7 | 4.0 | 6.0 | 26.9| 60.0| 86.0|
| 3            | 3.6 | 3.8 | 4.0 | 6.6 | 26.8| 59.9| 86.0|

Table 4. Kinetics of drying of fermented milk product with IR heaters during spraying at a temperature of 20°C.

| Height H, mm | 0   | 100 | 200 | 300 | 400 | 500 | 600 |
|-------------|-----|-----|-----|-----|-----|-----|-----|
| Experiment  |     |     |     |     |     |     |     |
| W %         |     |     |     |     |     |     |     |
| T, °C        |     |     |     |     |     |     |     |
| P, Pa        |     |     |     |     |     |     |     |
| 1            | 3.7 | 3.8 | 4.1 | 6.3 | 27.0| 60.2| 86.1|
| 2            | 3.7 | 3.7 | 4.0 | 6.0 | 26.9| 60.0| 86.0|
| 3            | 3.6 | 3.8 | 4.0 | 6.6 | 26.8| 59.9| 86.0|

From the analysis of these tables it can be seen, that in the process of sublimation dehydration, the product layer H in height can be divided into two sections: H1 – the site of removal of free crystalline moisture and H2 – the site of removal of bound moisture. Under the selected conditions and modes of drying without ultrasound H1 area is 1/3 H. Under the selected conditions and modes of drying with
ultrasound H1 plot is 1/2 H. When using an additional IR energy supply during evaporative self-freezing, the humidity in the upper layers of the product was lower by an average of 6%.

4.2. The Quality of drying
The drying results of sea-buckthorn and black-fruit-Rowan juices are presented in table 5 (without ultrasound).

| Table 5. Preservation of the nutritional value of the juice, depending on the method of drying and time to humidity 4 %. |
|-----------------------------------------------|
| **Product. Juice**                  | **The percentage preservation of vitamin C depending on the drying method** |
|                                    | **Proin** | **Proin, coactus gas fluere** | **Proin, ultrasound, coactus gas fluere** |
| Aronia chokeberry                   | 59        | 81                            | 86                            |
| Sea-buckthorn                       | 59        | 81                            | 86                            |

The results of drying fermented milk drinks enriched with two cultures-bifidobacteria and lactobacilli are presented in table 6 (conducted with ultrasound).

| Table 6. Recoverability depending on the drying method and time to a moisture content of 4 %. |
|-----------------------------------------------|
| **Product. Yogurt**                          | **The percentage recovery of GE healthcare tissue culture media depending on the drying method** |
|                                    | **Proin** | **Proin, coactus gas fluere** | **Proin, ultrasound, coactus gas fluere** |
| Bifidobacteriums                        | 19        | 59                            | 86                            |
| Lactobacilli                             | 10        | 58                            | 86                            |

The analysis of the experimental results shows that in the process of sublimation dehydration juice retains nutritional value in the intensification of drying both by microwave and ultrasound energy while ensuring the forced flow of gas through the dried product. With the intensification of the drying yogurt recoverability is achieved only when using all components proin, ultrasound, coactus gas fluere processing.

5. Discussion results
1. The method of preservation by vacuum freeze drying, allowing the most complete preservation of biologically active and nutrients of raw materials, can be promising for the production of qualitatively new products of functional purpose, priority in the national economic scale and competitive in the domestic market, provided the reduction of energy intensity of production.
2. Single vacuum cycle in continuous plants, the novelty of which is protected by patents [6,7], is a more effective technology of freeze drying, which improves the quality, energy and economic performance of the preservation process.
3. Rational distribution of additional types of energy of wave nature by the volume of drying reduces the energy intensity of the process [8] in comparison with the convection-vacuum one by 3.5-4 times (with a combined energy supply combining the type of energy, the stage of its use and the volume distribution).
4. Installation of the ICF-D-CE-L-02 with a capacity of 10 kg of evaporated moisture, and developed technology is transferred to MUSH, OOO and ZAO "CATHARSIS" for the production of special products from the freeze-dried fruit juice and freeze-dried yogurt with active lactobacilli and bifidus bacteria.

6. Conclusion
The use of freeze drying using a combined energy supply (IR and ULTRASONIC radiation, microwave energy and forced gas flow) can reduce the process time and increase the safety of ascorbic acid to 80-84% and the recoverability of bacteria in dairy products to 86%.

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