The object of this study is the heat treatment of multicomponent masses, for example, Jerusalem artichoke, pumpkin, and black chokeberry, during thickening and drying in an improved mobile functional apparatus for preliminary heat operations. The engineering solution is aimed at the implementation of resource-saving preliminary thermal operations of plant raw materials on mobile functional equipment. The structural difference of the device for the preliminary heat treatment of plant raw materials is the presence of a mobile platform with a carousel arrangement of rolling containers with changeable working elements. The device provides simultaneous implementation of thermal operations in three functional containers. The vacuum compartment and the steam generator with flexible technical lines are connected to functional tanks equipped with bubbler disks to improve heat transfer. The central platform has a microprocessor-based automatic control unit and a spring mechanism for lifting the cover equipped with Peltier elements for secondary heat conversion. The tanks are heated by a film resistive electric heater. Peltier elements are mounted on the inner surface of the cover to convert secondary heat for autonomous operation of the fan. For preliminary heat treatment of liquid media, the functional container is additionally equipped with a stirrer with a heated surface (the usable area of the thermal surface is 0.28 m^2).

The duration of reaching a stationary temperature regime (50 °C) of the multicomponent mass (Jerusalem artichoke – 50 %, pumpkin – 40 %, and chokeberry – 10 %) in a mobile device is 31.4 % less than in a classic design. The duration of the drying process in the functional device is 40 minutes, and in the conventional KVM-150 device – 60 minutes. A 1.8-fold decrease in the specific metal capacity was established. Total heat losses are reduced by 1.24 times, and the usable heating surface is increased by 1.3 times

Keywords: functional apparatus, plant raw materials, polycomponent semi-finished products, preliminary heat treatment

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STRUCTURAL IMPROVEMENT OF A MOBILE DEVICE FOR PRE-HEATED TREATMENT OF VEGETABLE RAW MATERIALS

Andrii Zahorulko
Corresponding author
PhD, Associate Professor*
E-mail: zagorulko.andrey.nikolaevich@gmail.com
Iryna Voronenko
Doctor of Economic Sciences, Senior Researcher
Department of Information Systems and Technologies
National University of Life and Environmental Sciences of Ukraine
Heroiv Oborony str., 15, Kyiv, Ukraine, 03041
Lyudmila Chuiko
PhD, Head of Research Department
Research Department**
Nataliia Tytarenko*
Eldar Ibaiev
FOP Ibaev Eldar Bayram ogli
Myronosytska str., 02, Kharkiv, Ukraine, 61051
Alla Solomon
PhD, Associate Professor
Department of Food Technologies and Microbiology***
Oksana Skoromna
PhD, Associate Professor
Department of Production and Processing Technologies
of Livestock Products***
Maksym Prykhodko
PhD student
Department of Management, Business and Administration**
*Department of Equipment and Engineering
of Processing and Food Production**
**State Biotechnological University
Alchevskykh str., 44, Kharkiv, Ukraine, 61002
***Vinnitsa National Agrarian University
Soniachna str., 3, Vinnitsa, Ukraine, 21008

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1. Introduction

The implementation of modern approaches in the agro-food sector ensures the production of food products based on plant raw materials and is one of the important directions of scientific research aimed at high-quality technological implementation under the conditions of resource-saving processing of raw materials. The introduction of innovative hardware and technological solutions makes it possible to improve heat treatment processes while preserving the func-

tional properties of the raw materials, which is important for the creation of semi-finished products with a high degree of readiness. The need for mobile technological solutions in the processing of plant raw materials is due to the growing demand for healthy food products that preserve the natural properties of components of plant origin [1]. Processing of plant raw materials requires a special approach immediately after harvesting in a mature state. Failure to comply with technological conditions at the stages from transportation to sale of the final product will inevitably lead to the loss of its valuable natural properties [2]. In particular, effective processing of agricultural products depends on the ability of technological equipment to adapt to changing conditions and minimize the impact of heat treatment during processing. Thus, according to research data, mobile hardware complexes make it possible to reduce the loss of nutrients, provide greater flexibility in the application of heat treatment methods, but they require high-quality implementation of the automatic packaging process [3, 4]. In addition, the increase in the efficiency of technological processes when using mobile plants for the processing of plant raw materials helps save resources and improve the quality of the final product [5].

The growing demand for healthy food products requires the improvement of pre-heat treatment technologies, including resource-saving processing of plant raw materials, as a natural source of physiologically functional ingredients with original rheological and organoleptic properties. The improvement of the equipment and technological component should be aimed at reducing energy consumption, shortening the duration of heat treatment, and improving the quality of multicomponent semi-finished products. The design and improvement of mobile devices will contribute to the flexibility of the use of devices and the preservation of the functional properties of raw materials, which meets the requirements of the sustainable development of the agro-food sector and increases the availability of functional products under various conditions.

2. Literature review and problem statement

The use of national resource capacities for the production of functional polycomponent semi-finished products of a high degree of readiness with specified structural and organoleptic properties is the most effective in the context of supporting the agro-industrial sector of the country [6]. However, there is a need to introduce various approaches to improve technological and hardware solutions. This will make it possible to implement resource-saving processing of plant raw materials into functional semi-finished products that can be used in modern technological processes, which requires verification studies [7]. Work [8] analyzes strategies for the development of functional healthy nutrition, taking into account the adaptation of consumers to the diversity of the color palette of products, which contributes to their visual appeal. In particular, when processing plant raw materials with a high content of carotene-containing substances, it is advisable to preserve the useful ingredients as much as possible, and when blending, it will be ensured to obtain products with an attractive color – increasing the interest of consumers in health products. Therefore, the optimization of technological and hardware solutions will make it possible to preserve the main properties of plant raw materials in the production of functional products. However, the feasibility of using one's own resources for the production of such products or obtaining semi-finished products with a high degree of readiness remain insufficiently considered.

Work [9] investigated the effect of berry consumption on human health, in particular on protection against cardiovascular diseases. However, questions regarding the importance of resource-saving processing of plant raw materials due to the seasonality of cultivation, the rapid change of thermolabile properties and the short period of use after harvesting remain unsolved. This is due to objective difficulties, such as the need for complex research, which is complicated by the insufficient material and technical base. One likely scenario is the adaptation of engineering solutions to the needs of the agro-industrial sector, namely the provision of resource-saving processing of plant raw materials under conditions of mobility of equipment and technological implementation. This, in turn, will lead to a reduction in costs for transportation and storage of plant raw materials and will provide the possibility of production of semi-finished products with a high degree of readiness directly on farms. The second way to solve these problems is to conduct interrelated research to form a generalized model, which will contribute to the implementation of innovative hardware and technological solutions. The study found that the consumption of berry juice has a positive effect on the lipid profile of a person, which emphasizes the relevance of processing plant raw materials. Regular consumption of multicomponent semi-finished products may also contribute to increased resistance to environmental stresses, which is important for certain population groups, such as military personnel and volunteers. The key component of the competitiveness of organic polycomponent semi-finished products is their quality, which leads to the need to improve production processes, including mobility and efficiency in the use of secondary energy, as shown in [10]. The processing of plant raw materials requires resource-saving equipment and technological approaches since the preservation of physiologically functional ingredients and the final quality of products depend on the number of intermediate and main technological operations. Most of the previous operations are implemented on single-operation devices with high energy and metal properties and without recuperative technologies of using thermal secondary energy. This leads to a decrease in the quality of resource-saving processing of plant raw materials in general, and therefore there is a need to improve existing hardware solutions and research aimed at increasing the efficiency of innovative technologies in the production of competitive products. Work [11] reports an analysis of the consumption of natural plant products in the daily diet of consumers to meet the needs of the body, which is relevant especially for people living under extreme conditions. However, the question of determining the ways of scientific and practical verification of multicomponent compositions not only for individual formulations of food products but also for multicomponent semi-finished products of a high degree of readiness, remains unsolved. It requires large-scale comprehensive research taking into account physical-chemical, rheological, and organoleptic properties, as well as their changes in the process of technological processing, which is quite a difficult task. One of the solutions to achieve the maximum preservation of the initial properties of plant raw materials is the implementation of innovative hardware and technological solutions aimed at mobility and functionality, in particular,

of thermal equipment. This approach will make it possible to use devices in the places of cultivation/harvesting of raw materials due to mobility. And multi-functionality will provide a solution to mono operation through the simultaneous implementation of several operations in one apparatus (blanching, extraction, drying, infusion, etc.), increasing the resource efficiency of the agro-industrial sector and the production of semi-finished products of a high degree of readiness.

Work [12] summarizes the disadvantages of the equipment for the concentration of plant raw materials in the production of blended semi-finished products of plant origin, namely the use of intermediate heat carriers with high energy and metal consumption. Issues related to the possibility of intensification of thermal devices for concentration and the influence of previous thermal operations with plant raw materials on the overall efficiency of the technological process are left out of consideration. The reason is the technological sector's use of conventional thermal equipment (single-operational, low resource-efficient, and with high intermediate heat carriers). In addition, the use of intermediate heat carriers makes it difficult to stabilize the temperature field under conditions of a significant duration of the process, does not make it possible to ensure mobility and resource saving, and reduces the quality of the products obtained. To increase the resource efficiency of the brewing process, the proposed actions are aimed at improving the vacuum evaporation apparatus by replacing the steam jacket with a film resistive electric heater of the radiation type with the simultaneous use of a unified stirrer to increase the usable heat exchange surface. This, in turn, makes it possible to qualitatively implement one of the available methods of production of functional semi-finished products, which is the use of modern approaches in the improvement of equipment and technological methods, in particular, to obtain vegetable polycomponent semi-finished products of a high degree of readiness. Such semi-finished products can be used both in finished form and as natural additives to various products to increase their nutritional value and reduce the use of synthetic components.

The improvement of the model structure of the mobile functional device for the implementation of heat and mass exchange processes during the processing of plant raw materials requires an analysis of the technological features of implementation and design requirements. In work [13] it is noted that preliminary heat treatment, including berries, significantly affects the physical and microbiological properties of the obtained products, which is related to the thermolabile properties of plant raw materials. The peculiarities of hardware implementation of intermediate thermal operations have traditionally been neglected. This is due to the fact that in most cases, technological operations are implemented on standard equipment, only optimization of technological processes is carried out. But this is not a guarantee of increasing the resource-saving indicators of the agro-food sector under the conditions of the production of healthy semi-finished products of a high degree of readiness and, in turn, requires the implementation of engineering solutions for a high-quality processing and production cycle.

The main heat and mass exchange processes include aging, blanching, drying, boiling, mixing, and extraction [14]. These operations are auxiliary technological operations for high-quality processing of plant raw materials, however, they artificially increased single-operation resource consumption, increasing the total duration of the technological cycle, affecting the quality of operations and plant raw materials. One of the reasons is the use of single-operation activities in the apparatus, which is connected with the low level of modernization of the processing and production complex, the decrease in the amount of cultivation of plant raw materials and the insufficient level of state support for farmland. Therefore, there is a need for a comprehensive approach aimed at ensuring multifunctionality and mobility of hardware and technological solutions for the simultaneous stabilization of thermolabile, physiological, and organoleptic properties. Thus, paper [15] first considers the physical and biochemical properties of food products, after which the basics of mass transfer, fluid movement, and heat transfer are described. Energy consumption, optimization methods, and the influence of thermal processes on the properties of products, the activity of enzymes and microorganisms are analyzed. Such an approach is relevant during the adaptation of modern hardware and technological solutions in the improvement of mobile functional apparatus for gentle preliminary heat treatment of plant raw materials to ensure effective and high-quality processing of plant products. Despite the prospects, the limitation of this process is the need for special technical solutions aimed at increasing resource efficiency and functionality. However, in most cases, preliminary heat and mass exchange operations are implemented on specialized one- and two-operation equipment. For example, heaters, blanchers, extractors, etc., which in most cases are low-efficiency and designed for high-performance flow lines due to their continuity, the use of secondary heat carriers, and therefore difficult to maintain. For example, in [16], the influence of heat treatment technology in the food industry and the achievement of a long shelf life were considered. Understanding the hardware-technological implementation of heat treatment depends on the efficiency of heat transfer in heat exchange systems, which in most cases depends on the functional properties of intermediate heat carriers, which are the main reason for the low productivity of the equipment. One of the effective solutions for increasing resource efficiency is the elimination of the intermediate component of heat exchange (intermediate heat carrier, systems of technological networks, and heat-generating devices) and the use of energy carriers with an even distribution of thermal energy.

For boiling natural raw materials, in addition to conventional vacuum evaporators, film evaporators are actively used, which are characterized by a high rate of heat exchange. However, the issues of the effectiveness of the application of hardware and technological solutions that reduce energy and metal consumption, in particular by minimizing the use of intermediate heat carriers, remain unresolved. This is due to difficulties with conventional equipment and high costs for increasing resource efficiency. One of the solutions is the improvement of existing thermal installations by eliminating intermediate heat carriers, reducing metal capacity, and using secondary thermal energy for technical needs. In [17], a comparison of a film evaporator with a conventional apparatus is given, where it is indicated that the duration of concentration in a film evaporator is 200 s, compared to 3600 s in a conventional one. However, the difference in mixer designs and equipment usage conditions should be taken into account. These results emphasize the need for research into innovative technologies to improve reactors. For example, work [18] considered the process of cooking baby puree at variable temperatures and blade

rotation frequencies, but without taking into account the influence of the heat transfer coefficient on rheological properties, which limits the full understanding of the process of thickening of raw materials. Thermolabile properties of plant raw materials require ensuring high-quality processing at all technological stages in short time intervals after harvesting, which is determined by international requirements for food products [19]. Thus, work [20] describes the process of concentrating fruit and berry pastes with an initial dry matter content of 9...15 % to the final content (29...31 %) at a surface load of 0.048...0.121 kg/m^2. The reduction of the specific energy consumption for heating the volume of the product unit was confirmed by calculation: the rotary-film evaporator – 547 kJ/kg in 75 s, compared to the basic vacuum evaporator – 1090 kJ/kg, respectively, in 1.08 h. However, the rapid development of the food industry and the industrialization of many countries also require the rational use of energy resources [21] for the formation of resource efficiency of functional equipment. Therefore, it is relevant to use national resources for the production of functional polycomponent semi-finished products, taking into account the optimization of technological and hardware solutions. This ensures resource saving, preservation of usable properties of raw materials, and improvement of product quality. However, existing equipment is mainly focused on single-operational processes, which reduces efficiency and complicates the implementation of innovative approaches. Particularly promising is the use of mobile multifunctional devices capable of performing several heat and mass exchange operations at the same time. The implementation of innovative hardware and technological solutions for mobile and resource-saving processing of heat-labile plant raw materials remains insufficiently researched. Therefore, experimental and practical research aimed at designing multifunctional mobile devices that will ensure stable product quality and increase the efficiency of thermal processes in a single system is expedient.

3. The aim and objectives of the study

The purpose of our research is to improve hardware and technological solutions aimed at designing a mobile functional device for the implementation of gentle processes of preliminary heat treatment of plant raw materials. This will make it possible to implement auxiliary technological processes for the production of polycomponent semi-finished products of a high degree of readiness based on plant raw materials in mobile equipment and technological complexes, which is relevant for high-quality processing of plant raw materials.

To achieve the goal, the following tasks were set:

– to propose possible directions for improvement of the model sample of the mobile functional device for the preliminary heat treatment of plant raw materials;

– to determine the effectiveness of the use of mobile functional apparatus in a number of basic technological operations aimed at resource-saving processing of plant raw materials.

4. The study materials and methods

The object of our study is the heat treatment of multicomponent masses, for example, Jerusalem artichoke, pumpkin, and black chokeberry, during thickening and drying in an improved mobile functional apparatus for preliminary heat operations. The research hypothesis assumes confirming the effectiveness of hardware and technological solutions aimed at improving the design of a mobile functional device for the preliminary heat treatment of plant raw materials. Peltier elements for the use of secondary heat are introduced into the design, the heat exchange surface is increased, and film electric heaters are used, which will significantly reduce energy consumption, shorten the duration of the processing process and increase the efficiency of the production of polycomponent semi-finished products.

Experimental and practical testing of the proposed innovative hardware and technological solutions in a mobile functional device for the implementation of gentle processes of preliminary heat treatment of plant raw materials was implemented at the State Biotechnology University (Kharkiv, Ukraine).

When determining the kinetics of heating in the proposed mobile functional apparatus, ripe vegetable raw materials were used: Jerusalem artichoke (variety "White"), pumpkin (variety "Muscat"), and chokeberry (variety "Nero"). The raw materials were collected in the current year on the farmlands of the Kharkiv front-line zone (with the assistance of the Lubotynska and Bogoduhivska communities) to support the agro-industrial sector. The use of Jerusalem artichoke of the "White" variety, pumpkin of the "Muscat" variety, and black-fruited chokeberry of the "Nero" variety for the production of healthy multicomponent semi-finished products is appropriate due to their high nutritional properties and functional components. Jerusalem artichoke is rich in inulin, which helps normalize metabolism, pumpkin provides carotenoids and trace elements, and chokeberry is a source of antioxidants and vitamins. The use of modern mobile devices makes it possible to preserve these properties thanks to gentle heat treatment, reduction of energy consumption, and resource-saving combination of ingredients to create products with increased biological value that meet the current requirements for healthy nutrition. It is necessary in the daily diet of consumer cooperatives, including for people under extreme conditions.

Research on obtaining a multicomponent puree-like mass based on the above-mentioned vegetable raw materials was carried out under the conditions of wiping on a double wiping machine (0.2...0.6 10^{-3} m). After that, an intermediate technological operation was implemented to blend the multi-component mass in the ratio of 50 % Jerusalem artichoke, 40 % pumpkin, and 10 % chokeberry. Black-fruited aronia additionally underwent an intermediate thermal drying operation as it has a high content of thermolabile polyphenols, anthocyanins, and antioxidants, which critically affect the functional value of the obtained products. Studying parameters of heat-labile raw materials will make it possible to optimize drying parameters and minimize loss of heat-labile substances. For pumpkin and Jerusalem artichoke with the main more heat-resistant components (carotenoids, inulin), therefore, there is no expediency of carrying out drying processes. The obtained homogeneous puree-like mass was loaded with a gear pump to the model structure of the functional apparatus, followed by boiling to the consistency of a pasty semi-finished product with a dry matter content (DM) of 20–30 %. To confirm the reliability of experimental data, the research was repeated 5 times with a relative error of no more than 3 % using conventional methods for processing experimental and practical data on thermal processes.

5. Results of implementation of hardware and technological solutions for preliminary heat treatment

5. 1. Improvement of the prototype of a mobile functional apparatus for preliminary heat treatment of plant raw materials

Hardware and technological solutions aimed at the intensification of the heat and mass exchange apparatus for resource-saving implementation of intermediate technological operations of preliminary heat treatment are implemented by:

– the functional apparatus is equipped with a mobile platform for the carousel arrangement of roll-in functional containers with replaceable working elements. The central mobile platform is equipped with an automatic control unit based on the "OVEN" microprocessor (Ukraine, Kharkiv), a vacuum compartment, a steam generator, and a lifting rail with a rotary spring and retractable lid lifting mechanism;

– the use of roll-on functional containers with replaceable working bodies (mixer with a heated surface, mesh trays in a frame deck, and perforated container with internal distributors) for preliminary heat treatment of vegetable raw materials.

The mobile functional device for the preliminary heat treatment of plant raw materials (Fig. 1) structurally represents a mobile platform 1 with the possibility of a carousel arrangement of rolling functional containers 2 with replaceable working elements.

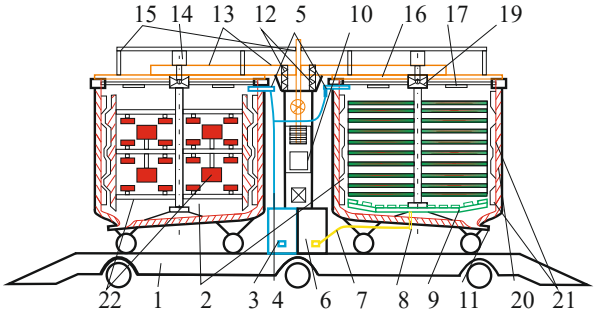

Fig. 1. Schematic diagram of a model sample of a mobile functional device for preliminary heat treatment of plant raw materials: 1 — mobile platform; 2 — roll-in functional containers with replaceable working elements; 3 — vacuum separation; 4 — flexible technical highway; 5 — vacuum nozzle; 6 — steam generator; 7 — flexible rubber main line; 8 — technical pipe; 9 — bubbler disk; 10 — automatic control unit based on the "OVEN" microprocessor; 11 — drain pipe; 12 — spring mechanism; 13 — rotary lifting rail; 14 — electric motor; 15 — retractable mechanism for lifting the cover; 16 — cover; 17 — Peltier elements; 18 — autonomous fan; 19 — quick disconnect couplings; 20 — film-like resistive electric heater of the radiating type (FIEHRt) [22]); 21 — technical separators; 22 — a stirrer with a heated surface

The device makes it possible to simultaneously implement intermediate thermal operations in 3 functional rolling containers 2, equipped with a stirrer with a heated surface, mesh trays in a frame deck, and a perforated container with internal distributors. In the center of the mobile platform, the following is mounted: a vacuum compartment 3 with the possibility of connecting a flexible technical line 4 with vacuum nozzles 5 (adjustable vacuum up to 16 kPa). There is also a steam generator 6 with a flexible rubber line 7 and technical nozzles 8. In particular, the functional rolling containers 2 with mesh trays in the frame deck and a perforated container with internal distributors in the lower part have a bubbler disk 9. An automatic control unit based on a microprocessor is mounted on the central platform "OVEN" 10 for monitoring vacuum, temperature, rotation frequency of working elements of functional containers 2, and the system of automatic opening of the drain nozzle 11.

In the upper part of the central platform, a spring mechanism 12 is mounted, which has a rotating lifting rail 13, on which electric motors 14 for the working bodies of functional containers and a sliding mechanism 15 for lifting the cover 16 are mounted.

Peltier elements 17 are mounted on the inner surface of lids 16 of the functional containers, which convert secondary heat (at 50 °C, a low-voltage secondary voltage of 4.0 W is formed), which is enough for the autonomous operation of fan 18. This allows for forced cooling of the internal working space of the central platform. Structurally, the lids have a rubber contact seal with snap-on bolt fasteners to prevent depressurization during vacuuming and technical windows for introducing recipe ingredients. The working bodies of the roll-down functional containers 2 are installed in quick-disconnect couplings 19, ensuring their quick replacement and maintenance, including disconnection of the electric motor 14 and roll-back of the container for further technological operations.

In order to increase the structural efficiency of the roll-in functional containers 2, the conventional heat supply of the intermediate heat carrier is replaced by electric heating with a film-like resistive electric heater of the radiating type 20. The inner surfaces of the roll-in functional containers have technical separators 21 of the liquid and vapor-air medium for the formation of turbulent properties in the wall layers, preventing, among other things, overheating of raw materials in contact space. In order to intensify the heat processes for the preliminary heat treatment of liquids and suspensions, the rolling functional container is additionally equipped with a stirrer with a heated surface 22 (the usable area of the heat surface is 0.28 m^2). Thus, ensuring full mixing of the liquid medium and uniformity of heating of liquid layers, which is especially important during the heat treatment of vegetable semi-finished products, in particular multi-component ones under conditions of homogeneous mixing.

5. 2. Experimental and practical testing of the main processes of preliminary heat treatment of plant raw materials

One of the main auxiliary heat and mass exchange operations in the processing of vegetable raw materials is the technological processes aimed at heating and boiling pre-shredded homogeneous puree-like mass. Including thickened paste-like semi-finished products of a high degree of readiness with subsequent production of functional products on their basis without the use of conventional equipment for boiling (concentration). The practical verification of the effectiveness of the model design of the functional apparatus was carried out under the conditions of determining the kinetics of heating of a puree-like multicomponent vegetable semi-finished product. The kinetics during the process of boiling the pureed mass to a pasty state with a final content of 20...30 % SR (Fig. 2) were studied under conditions of comparison of the implementation of the process in the conventional MZ-2S-316 structure.

The duration of reaching the stationary gentle temperature range (50 °C) of boiling of the multicomponent mass

during boiling in the model design of the functional apparatus with a stirring device with a heated surface is 240 s. And in the conventional design MZ-2S-316 – 350 s, respectively (the decrease is actually 31.4 %).

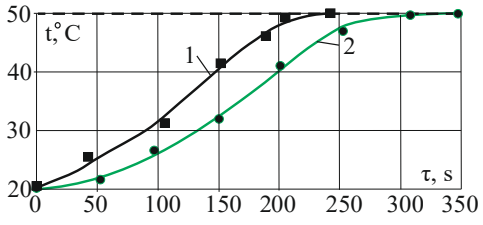

Fig. 2. Verification-experimental data on the heating kinetics of a vegetable polycomponent semi-finished product:
1 – model design of the functional apparatus;
2 – conventional MZ-2S-316 structure

A study of the preliminary technological operation of drying black chokeberry to a content of 25 % DM (80 % DM initial moisture content, Fig. 3) was carried out. Auxiliary thermal technological operation was implemented by using a functional apparatus with a rolling functional capacity with a variable working body in the form of mesh pallets in a frame deck, under the conditions of comparison of the process in KVM-150.

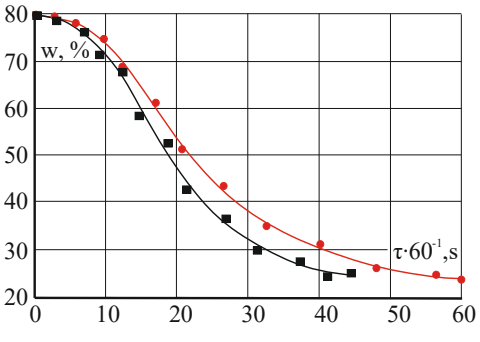

Fig. 3. Kinetics of the black chokeberry drying process:
■ – functional apparatus; ● – KVM-150

The duration of the drying process in the functional device is 40 min, and in the conventional KVM-150 device – 60 min, respectively, which is explained by heating not by an intermediate heat carrier, but by an electric heater. In the course of the practical test, a comparison of the main technical parameters of the functional apparatus with electric heating and functional capacities and the conventional MZ-2S-316 design was performed (heat losses to the environment were neglected in Table 1).

A comparison of the main technical indicators (Table 1) confirms the structural efficiency in reducing the specific metal capacity by 1.8 times, total heat loss by 1.24 times. The usable heating surface has increased by 1.3 times, other indicators also have resource-saving advantages.

6. Discussion of results related to the effectiveness of the hardware and technological solutions implemented in the mobile functional device

The implemented hardware and technological solutions are aimed at increasing the competitive properties of mobile functional equipment for the implementation of preliminary thermal operations of processing plant raw materials under the conditions of elimination of intermediate heat carriers and increasing the heat exchange surface. The use of collapsible functional containers and the mobility of the complex make it possible to simultaneously implement 3 auxiliary thermal operations under the conditions of the location of raw material processing at the collection points, reducing the operational duration and preserving the heat-labile properties of raw materials. The use of Peltier elements to power the autonomous fan reduces energy costs for cooling the technical space of the central panel of the functional device. Paper [12] considered the importance of improving functional devices for the processing of plant raw materials to combine the processes of preliminary heat treatment, and therefore, reducing energy costs and increasing the efficiency of processing. Study [17] shows that the integration of the latest technologies for mobile devices, such as the use of modular heat pumps, significantly increases productivity, and reduces the negative impact on the quality of raw materials, in particular, due to the optimization of temperature regimes. The use of conventional thickeners [7] is complicated by the presence of a steam component, which increases the energy and metal consumption, as well as the costs of transportation and storage of raw materials, which leads to the loss of valuable physiologically functional ingredients. In work [24], studies of boiling puree in a vacuum-evaporator with an improved stirrer are reported, but the use of steam can lead to hydraulic shocks. Rejection of intermediate heat carriers increases operational properties, reduces metal density, and improves uniformity of heat supply. Paper [25] presents a practical solution for a vacuum-evaporating apparatus based on the electrical method of heat supply, which demonstrates significant competitive advantages. Confirming the importance of improving the designs of mobile devices to achieve the maximum effect with the maximum resource saving of the agro-food sector.

Table 1

Technical parameters of the improved functional apparatus with rolling containers (a functional container with a stirrer with a heating surface was used) in comparison with the conventional MZ-2S-316 structure

Technical indicator	Advanced functional apparatus	The classic design of the steamer (MZ-2S-316)
Technical weight of the structure	$m=m^*-m_{shirts}+m_{PpREnVT}$=380–120+10=270 kg	m^*=380 kg
Useful heating surface	$F=F^*+F_{stirrers}$=0.98+0.28=1.26 m^2	F^*=0.98 m^2
The heat of heating the test sample	$Q_{pr}=m\cdot c\cdot(t_k-t_n)$=240·3.7·(55–20)=31 080 kJ	$Q_{pr}=m\cdot c\cdot(t_k-t_n)$=240·3.7·(55–20)=31080 kJ
The heat of heating the device	$Q_{ap}=m_1\cdot c_c\cdot(t_2-t_1)$=200·0.48·(55–20)=3360 kJ	$Q_{ap}=m_1\cdot c_c\cdot(t_2-t_1)+m_2\cdot c_c(t_3-t_1)$= =200·0.48·(55–20)+138·0.48·(145–20)=11640 kJ
Total heat consumption	Q_{zag}=34440 kJ	Q_{zag}=42720 kJ
Specific metal capacity	$m=M/F$=270/1.26=214 kg/m^2	$m=M/F$=380/0.98=387 kg/m^2

Note: – information on the basic design of the MZ-2S-316 is taken from [23].*

We have improved the model structure of a mobile functional device for the implementation of preliminary thermal processes during the processing of plant raw materials. The structural difference is mobility due to the mobile platform (Fig. 1, item 1), the use of roll-up functional containers with changeable working elements (Fig. 1, item 2) with the possibility of simultaneously implementing three technological operations. The central panel (Fig. 1) has a vacuum compartment (3), a steam generator (6), an automatic control unit based on the "OVEN" microprocessor (10), a technical unit (a spring mechanism (12), a rotary lifting rail (13), an electric motor (14) and a retractable mechanism for lifting the lid (15). The device works with roll-in functional containers with replaceable working bodies: a stirrer with an additional heating surface (0.28 m^2, Fig. 1, item 22), mesh trays in a frame deck and a location in the tender part of the bubbling disk (Fig. 1, item 9), and a perforated container with internal distributors for preliminary heat treatment of vegetable raw materials.

We have determined that the duration of exposure to the temperature regime (50 °C) for a multicomponent mass based on Jerusalem artichoke (50 %), pumpkin (40 %), and chokeberry (10 %) when boiled in a model apparatus is 31.4 % less than in the conventional structure (Fig. 2). The duration of the drying process in the functional device is 40 minutes, and in the conventional KVM-150 device – 60 minutes (Fig. 3). A comparison of the main technical indicators confirms a decrease in the specific metal capacity by 1.8 times, total heat loss by 1.24 times, and an increase in the usable heat exchange surface by 1.3 times (Table 1). The practical significance of our research is the improvement of a mobile functional device for resource-saving heat treatment of plant raw materials for the production of health-promoting polycomponent semi-finished products with high biological value. Thanks to the design features of the device (carousel arrangement of containers, heat recovery, optimization of heat exchange), energy consumption is reduced, the duration of heat treatment is reduced, and the maximum preservation of valuable components of raw materials, in particular, heat-labile substances of black chokeberry, is ensured. This contributes to the production of quality healthy food products adapted to the needs of the modern consumer.

One of the limitations during the study of the apparatus was the establishment of a clear stabilization of the temperature on the heating surface, which is ensured by the use of a stirrer with an additional heated surface (Fig. 1, item 22).

The main drawback is the difficulty of using mobile functional devices at high-performance processing enterprises, however, in the work, the main attention is paid to ensuring the mobility of the equipment. It is important to note that neglecting these recommendations can reduce the competitiveness of the improved device design. Further research will be aimed at the formation of resource-saving recommendations for the use of the proposed device, taking into account the equipment-technological features and thermolabile properties of plant raw materials.

7. Conclusions

1. We have improved design of the mobile functional apparatus for the preliminary heat treatment of plant raw materials, which has a platform for the carousel arrangement of rolling functional containers with replaceable working elements. Providing simultaneous implementation of thermal operations in 3 functional rolling containers. In the center of the mobile platform, the following is mounted: a vacuum compartment with the possibility of connecting a flexible technical main with vacuum nozzles. A steam generator with a flexible rubber main line and technical nozzles is placed. Functional roll-up containers with mesh trays in the frame deck and perforated container with internal dividers in the lower part are equipped with a bubbler disk. An automatic control unit based on the "OVEN" microprocessor is mounted on the central platform.

In the upper part of the central platform, a spring mechanism with a rotating lifting rail is mounted on which electric motors for working bodies of functional containers and a sliding mechanism for lifting the lid are mounted. On the inner surface of the lids, Peltier elements are mounted for the conversion of secondary heat (at 50 °C, respectively – 4.0 W) for autonomous operation of the fan. The lids have a rubber contact seal with quick-release bolt locks to prevent depressurization during vacuuming and technical windows for introducing recipe ingredients. The working bodies of the roll-in functional containers are installed in quick-release couplings. The heating of the roll-on functional containers is carried out by a film-like resistive electric heater of the radiating type. The inner surfaces of functional containers have technical separators for liquid and vapor-air medium. For preliminary heat treatment of liquid media, the container is additionally equipped with a stirrer with a heated surface (the usable area of the thermal surface is 0.28 m^2).

2. The duration of reaching a stationary temperature regime (50 °C) of the multicomponent mass (Jerusalem artichoke – 50 %, pumpkin – 40 %, and chokeberry – 10 %). When brewing in a model functional apparatus with a stirring device with a heated surface, it is 31.4 % less than in the conventional design. The duration of the drying process in the functional device is 40 minutes, and in the conventional KVM-150 device – 60 minutes. When comparing the main technical indicators, a decrease in the specific metal capacity by 1.8 times was established. Total heat losses are reduced by 1.24 times, and the usable heating surface is increased by 1.3 times.

Conflicts of interest

The authors declare that they have no conflicts of interest in relation to the current study, including financial, personal, authorship, or any other, that could affect the study, as well as the results reported in this paper.

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Data availability

All data are available, either in numerical or graphical form, in the main text of the manuscript.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the current work.

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