The object of this study is the implementation of low-temperature processes for the production of meat and vegetable products under the conditions of adding a dried semi-finished product of a high degree of readiness to the recipe when using the designed universal rotary device of continuous action. The rotary device of continuous action for low-temperature processing of meat and vegetable products with a cylindrical working chamber is heated by a film-like resistive electronic heater of the radiating type. It has a stationary wall (with a technical door for unloading and loading the device) and a technical wall (with an opening angle of 90°). On the inner surfaces of the walls, inclined converging ribs with an angle of 25° are installed, which are covered with an electric heater. Semi-finished meat and vegetable products are loaded onto carts with technological containers and mounted on a frameless drum (rotation frequency 0.03...0.06 s^{-1}). The device converts secondary thermal energy into low-voltage power supply voltage (~3...8 W) for autonomous operation of fans.

The proposed integrated adaptive mechanism for the system of complex interaction of the agricultural, processing, and production sectors implies the formation of resource efficiency of production processes from "farm to table". The designed device implements the process of frying meat-vegetable bread under conditions of reaching 80 °C in the center of the product. The obtained temperature field data confirm the uniformity of the temperature field during frying of the product (cooking readiness of the product at the initial weight of 650±20 g – 4.0 hours). The introduction of a multicomponent dried fraction based on potatoes, Jerusalem artichokes, zucchini, and carrots into the recipe of meat-vegetable bread reduces the weight loss of the semi-finished product during frying by 12.3 %. It increases the content of calcium, phosphorus, vitamin C accompanied with a decrease in energy value by 28.1 %

Keywords: meat-vegetable products, multicomponent vegetable dried semi-finished product, frameless technology, temperature field uniformity

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DESIGN OF A UNIVERSAL LOW-TEMPERATURE ROTARY APPARATUS FOR MAKING MEAT AND VEGETABLE PRODUCTS CONSIDERING THE INTEGRATED ADAPTIVE MECHANISM

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1. Introduction

The national food security of European countries needs to take into account environmental, man-made, military, and other factors that lead to a decrease in the immune component, manifestations and exacerbation of various diseases and exposure to extreme conditions [1]. The available assortment of the agro-industrial sector of Ukraine has significant potential, even under conditions of full-scale military aggression. The challenges of being under extreme conditions, pandemics and targeted support of global food security require the search and implementation of innovative resource-saving competitive solutions for the agro-industry of European countries. The limitation of the available range of food products is the use of artificial foreign ingredients in the recipes, the lack of physiologically functional ingredi-

ents (PFIs) to support the immunity of the human body, and the use of highly energy-consuming equipment and technological agro-industrial solutions. In order to maintain the food security of European countries, the complex interaction of the agricultural sector by using its own raw plant base to minimize the content of artificial additives in interaction with resource-saving innovative solutions of the processing and production complex is necessary. The introduction of natural PFIs into the recipes of various food products under the conditions of low-temperature production processing, including meat products, could enable the production of competitive products with original rheological and organoleptic properties [2]. This, in turn, requires the modeling and development of modern competitive mechanisms for the agri-food sector to support and form the country's food security under the conditions of full-scale military operations and rapid post-war recovery.

Available hardware and technological solutions for the production of meat products through the use of high-temperature heat carriers and artificial ingredients do not fully meet the needs of consumers under the conditions of food security in the country [3]. The implementation of complex resource-saving mechanisms aimed at the development of a universal low-temperature rotary device for the production of meat and vegetable products, taking into account competitive mechanisms of agro-food security, will support the country's economy. The use of our own raw material base will provide support to the agricultural lands of Ukraine at the stage of growing high-quality plant raw materials with further low-temperature equipment and technological solutions for obtaining natural semi-finished products of a high degree of readiness. The addition of meat products to recipes will ensure the expansion of the functional properties of products with maximum preservation during low-temperature processing and is an urgent task of the agri-food sector for Ukraine's own food security and the support of European countries.

2. Literature review and problem statement

Ukraine's food security under conditions of full-scale military aggression depends on a coordinated state policy of the agro-industrial sector aimed at supporting and developing agro-technologies, implementing innovative solutions of processing and production complexes, and taking into account the needs of consumer cooperatives [4]. A highly profitable food system combines individual sectors to quickly respond to changing environmental, man-made, military, and other crisis test factors, providing support for consumer cooperatives. The rapid change under the conditions of human life requires the state, including the agri-food sector, to take quick actions aimed at providing the needs of cooperatives with high-quality functional food products in compliance with competitive mechanisms.

The development of rural areas is a complex and dynamic phenomenon, the effectiveness of which depends on food security and economic activity of the population. The relevance of these issues is enhanced by the unprecedented challenges for Ukraine and the transformation of the legal field under martial law. The purpose of this study is to determine the factors and determinants of human capital development in rural areas of Ukraine, taking into account the experience of the EU countries under the conditions of global challenges. It has been substantiated that the policy adopted in the state to ensure the development of rural areas on the basis of inclusiveness should be based on balanced tools, methods and levers capable of minimizing external and internal threats to agribusiness. In essence, the capabilities and abilities of people for economic and social activities, as well as for their own development, are critically important. It has been proven that the determining factor in this process should be human capital. The motivation of economic activity in the village is singled out from personal factors. In its absence, all prerequisites for urbanization are formed. In this context, the upward dynamics of the share of the urban population in EU countries was analyzed and revealed, which can become an obstacle for business development in rural areas. One of the unresolved issues is the introduction of adapted competitive resource-saving mechanisms based on comprehensive support and development of small businesses in rural areas (farmlands) for growing a high-quality own raw material base. In the future, processing into semi-finished products of a high degree of readiness and introduction into food recipes is possible, thereby ensuring the production of a wide range of functional products. The territorial location of Ukraine allows growing natural raw materials with functional and original organoleptic and rheological properties using eco-technologies. Grown heat-labile plant raw materials require resource-saving low-temperature processing technologies directly at the places of cultivation, in particular, into semi-finished products with a high degree of readiness. Semi-finished products have a wide range of use as independent products and recipe ingredients of food products, artificially increasing the PFI content and providing original rheological and organoleptic properties. This will ensure the demand of consumer cooperatives and support the food security of European countries under the conditions of resource-saving technological approaches to the material and technical base, environmental safety, high profitability of the agro-food sector [5] and is an actual area of research. The proposed mathematical approach considers the peculiarities of the export of Ukrainian agricultural products to the EU, thereby limiting the combined resource-saving approach from the cultivation of one's own raw vegetable raw materials to the production of food products. Work [6] examines the feasibility of using plant raw materials in various food recipes to artificially increase functional properties and obtain original rheological and organoleptic properties, replacing synthetic ingredients. In the course of research, a conclusion was drawn regarding the use of berries for the further production of functional products, which represent an outstanding economic potential for maintaining human health and functioning. However, further research aimed at the formation of resource-saving hardware and technological solutions for the combined support of own agro-industrial complexes remains to be carried out. For example, in work [7], study was performed on the production process of fried chopped meat semi-finished products with the addition of blended dried semi-finished products based on Jerusalem artichoke, pumpkin, and zucchini to the recipe. It was established that the water-absorbing capacity is 6 % higher than that of bread, while an increase in the content of potassium, calcium and dietary fibers and other functional ingredients in the finished meat product is observed. However, the effectiveness of the use of low-temperature processing of meat products with plant raw materials and the technology of obtaining dried heat-labile raw materials remains to be

investigated, requiring further research in this area for the formation of resource-saving equipment and technological solutions.

In works [8, 9], the structural and technological shortcomings of the heat and mass exchange equipment, which are related to the energy and metal consumption of the equipment for drying raw materials under the conditions of the use of high-temperature media, lack of mobility and resource-saving technologies, are given. The problem of these studies is the low level of resource efficiency of hardware and technological solutions, which, in turn, leads to the loss of the initial properties of raw materials and a decrease in the final quality of finished products. In addition, there are no studies on the feasibility of introducing high-grade vegetable semi-finished products into the recipes of meat products with the aim of possible replacement of recipe (synthetic ingredients) to improve the functional properties of finished products. In particular, paper [10] draws attention to the formation of government programs aimed at improving the quality of nutrition to maintain human health, in particular, in the context of consumption of meat delicacies. However, issues related to competitive consumer demand for meat products enriched with natural ingredients without disclosing the technological features of production and the presence of synthetic ingredients remain neglected, requiring practical research in this area. One of the ways to solve the above-mentioned shortcomings is the formation of competitive mechanisms for combining the agro-food sector under the conditions of using modern resource-saving technologies for the production of functional meat and vegetable products on modern mobile low-temperature equipment. One of the solutions is reported in [11], in which the method of production of chopped meat semi-finished products with the addition of dried semi-finished products in the IR field at a temperature of 45...60 °C to the final dry matter content of 12...15 % is considered. In addition, the implementation of heat treatment of chopped meat products was carried out in an apparatus with functionally closed environments when compared with the traditional method. It was established that the introduction of a dried semi-finished product based on Jerusalem artichoke and zucchini into the recipe of chopped meat semi-finished products reduces the total weight loss of meat culinary products by 11.9 % and increases the nutritional value of the experimental sample.

Taking into account the realities, there are needs for modeling and development of universal resource-saving equipment for processing and production facilities, hotel and restaurant complexes (home and field conditions) in the production of functional meat and vegetable food products. The practical implementation of innovative hardware and technological solutions will allow maintaining the country's food security in the following aspects:

– effective use of the agricultural sector's own plant resources, grown according to resource-saving technologies with reduced costs (energy and material) for production. This is not only economically beneficial but also will allow maintaining own processing and production capacities in wartime, price stability for semi-finished products with a high degree of readiness and food products, which is important for consumer cooperatives during crises;

– the production of vegetable semi-finished products with a high degree of readiness leads to the formation of a full-fledged diet of safe natural food products. This is especially important for functional and curative-prophylactic products, which must meet strict standards to support the health of consumers;

– increasing equipment and technological mobility under the conditions of the location of processing complexes in the places of collection of own plant raw material base of different regions, which is especially important during war or emergencies. This ensures the uninterrupted supply of semi-finished products of a high degree of readiness and food products to the places with the greatest need, including displaced persons, the military, doctors, and volunteers;

– design and implementation of universal hardware and technological solutions aimed at strengthening national food security, allowing the country to be less dependent on food imports and stably provide the population with the necessary food products under crisis conditions.

Paper [12] considers the prospects of using Jerusalem artichoke as a natural raw material containing important inulin, an unaltered carbohydrate of the fructose type, which acts as a dietary fiber. The introduction of an inulin-containing component into the content of multicomponent dried semi-finished products of a high degree of readiness increases the demand of consumer cooperatives at the mental level. In addition, meat-based foods with inulin provide improved digestion while reducing the risk of disease (constipation, intestinal disease, etc.). Inulin also acts as a prebiotic ingredient in healthier meat recipes, as it is a fat substitute and dietary fiber booster. The combination of Jerusalem artichoke with starch-containing potatoes, dietary zucchini, and carotene-containing carrots, which is a traditional raw material base of Ukraine with a low cost, is relevant for further production of dried semi-finished products with a high degree of readiness. This, in turn, confirms the expediency of using the semi-finished product in the recipes of meat and vegetable products, but it requires detailed experimental and practical research aimed at resource-saving low-temperature processing of plant raw materials and meat products under the conditions of competitive mechanisms.

Paper [13] investigated the deep-frying of pork with the determination of changes in the physical properties of the initial meat raw material and the finished culinary product. Frying was carried out in sunflower oil at a temperature of 90...110 °C and a moisture diffusion coefficient from 1.5 to $30.2 \cdot 10^{-9}$ m^2/s, confirming the effect on the density and organoleptic properties of the finished product. However, during frying, the influence of thermal-physical properties of the frying surface was not taken into account, which is explained by the complexity of research in real time and requires research aimed at determining the achievement of uniform heat supply. Also, in work [14], the heat and mass transfer during frying of chopped minced meat products was determined in direct contact of the test sample with heated plates (98...110 °C) for 4 min with the appearance of a crust on the surfaces of the product. However, the work does not focus on the features of heat transfer, which affects the uniformity of the temperature field and the expediency of low-temperature processing to minimize the formation of a hard crust and significant mass loss. One of the solutions for low-temperature processing of meat raw materials is reported in work [15] through the development of an apparatus for the production of meat delicacies with heating of the working surface by a radiation-type electronic heater. According to its functional properties, the device provides the possibility of cooling the delicacy up to 25...30 °C with autonomous fans, and a comparative analysis of the heat

treatment of the meat delicacy in the traditional way confirms the effectiveness of this technology. The proposed apparatus is highly specialized for the assortment of meat delicacies, which necessitates the search for resource-saving technologies with the possibility of implementing hardware and technological solutions aimed at simultaneous low-temperature processing of a certain assortment of meat and vegetable products. In work [16], research is given on the popular technology – processing under high hydrostatic pressure under the conditions of the "sous-vide" method, and an assessment of the quality of veal cutlets is carried out. Heat treatment of experimental samples without and with the addition of vegetable raw materials to minced meat under "sous-vide" at pressures from 350 to 600 MPa with a duration of 5 to 15 minutes at a temperature of 55...65 °C. According to organoleptic indicators, cutlets with veal and vegetable raw materials have a certain advantage in terms of juiciness and original taste properties. For example, work [17] investigated the change in the mass loss of minced meat products during frying under the conditions of adding oats to the recipe, which is beneficial for health and has the mechanical and physicochemical properties of ground beef. However, issues related not only to the advantages of using dried vegetable semi-finished products in chopped meat products but also to the provision of adsorption properties by natural components, remain undetermined. This is due to the complexity of the studies required when directly implementing the frying process in terms of taking into account the method of heat supply, heating uniformity, temperature range values, etc. One of the solutions is given in [18] during the production of combined health-improving meat-vegetable products to meet consumer demand for new-generation functional products for sale in craft industries. A universal device for heat treatment of meat and vegetable products under hot and cold smoking conditions based on a radiation-type electric heater has been designed. The device uses Peltier elements to obtain a low-voltage supply voltage (~3...4 W) from secondary heat conversion. In the course of research, the uniformity of the temperature field of the meat-vegetable product was confirmed. Adding dried semi-finished products to the recipe of meat products made it possible to increase the yield of the product and the mass fraction of protein, which in turn confirms the relevance of experimental and practical research taking into account the properties of the multicomponent dried mixture. Taking into account the features of resource-saving low-temperature processing of plant raw materials is aimed at maximum preservation of heat-labile ingredients, and the subsequent introduction of meat semi-finished products into the recipes under conditions of gentle heat treatment will allow obtaining a diverse range of meat and vegetable products. The implementation of innovative engineering solutions aimed at the uniformity of heat supply during low-temperature processing and the use of secondary thermal energy for technical needs under conditions of equipment mobility will make it possible to form a universal device.

Innovative hardware and technological solutions are aimed at the uniformity of heat supply during low-temperature processing and the use of secondary thermal energy for technical needs under the conditions of resource-saving universal equipment. The introduction of adaptive mechanisms for combined cooperation of the country's agro-food sector is a component of supporting food security in the production of competitive functional meat and vegetable products with the addition of dried semi-finished products of a high degree of readiness. This, in turn, will provide for the following:

– to increase the efficiency of production under conditions of uniform heat supply during low-temperature processing of plant and meat raw materials to preserve the natural properties of the initial and obtain the original organoleptic properties of finished functional products;

– the processing of plant raw materials into dried semi-finished products of a high degree of readiness improves the shelf life and simplifies logistics, and the introduction of them into the recipes of food products increases the functional and therapeutic and preventive properties, contributing to the competitiveness of products on the domestic and foreign markets;

– to use secondary thermal energy for technical needs, reducing the total energy costs of production, making the process more resource-saving and will contribute to the sustainable development of the agro-food sector in terms of reducing the impact on the environment;

– deploying mobile complexes and using resource-saving technologies will allow prompt response to regional needs, especially in areas with limited access to stationary production facilities. This is important for ensuring food security at war and post-war reconstruction. In addition, the implementation of an adaptive mechanism will ensure comprehensive competitive cooperation of agro-industry in the production of products for displaced persons, military personnel, doctors, volunteers, and other persons under extreme conditions. And the introduction of resource-saving equipment will contribute to the stability and reliability of agro-food systems of Ukraine, which is a key factor for maintaining food security under the conditions of post-war recovery and sustainable development. This confirms the practical need to conduct experimental and practical research "from the field to the table" in this area under the conditions of full-scale military operations for rapid post-war recovery.

3. The aim and objectives of the study

The purpose of our research is to design a universal low-temperature rotary device of continuous action for the production of meat and vegetable products. The introduction of vegetable semi-finished products into the recipes of meat products will support the country's own agro-industrial sector and expand the range of functional meat and vegetable products with original organoleptic properties. The use of modern engineering solutions in the development of a resource-saving device realizes the production of various meat products (sausage products, sausages, breads, etc.) with original natural properties and PFI of meat products based on vegetable semi-finished products with a high degree of readiness.

To achieve the goal, the following tasks were set:

– to build an experimental model of a universal low-temperature rotary device for the production of meat and vegetable products;

– to propose an integrated adaptive mechanism for the system of complex interaction of agrarian, processing, and production sectors for the formation of technology "from the goat to the table" and to check the effectiveness of engineering solutions during experimental and practical testing of low-temperature production of meat and vegetable products.

4. The study materials and methods

Experimental and practical research was carried out at the State Biotechnological University (DBTU, Kharkiv, Ukraine). The object of our study is the implementation of low-temperature processes for the production of meat and vegetable products under the conditions of adding a dried semi-finished product of a high degree of readiness to the recipe when using the designed universal rotary device of continuous action.

To obtain a multicomponent dried semi-finished product of a high degree of readiness, the own raw material base of the farmlands at the front-line Kharkiv oblast was used. The 4 most available (popular) varieties of vegetables were pre-selected: potatoes ("Slovyanka" variety, DSTU 9221:2023), Jerusalem artichoke ("Dietic" variety, DSTU 8046:2015), carrots ("Karotan" variety, DSTU 7035:2009), zucchini (variety "Zolotynka", DSTU 318-91), which are sources of natural nutrients and PFIs [19–21].

The multicomponent dried semi-finished product with a high degree of readiness was obtained at the DBTU's laboratory facilities under the conditions of low-temperature heat-mass exchange processing with the passage of ripe vegetable raw materials from previous operations (washing, inspection, slicing (5...10 mm)). After cutting, the potatoes were additionally washed under running water to minimize starch residues on the cut surfaces, followed by blanching with hot steam (105...108 °C for 2...4 min). Jerusalem artichoke was blanched with hot steam for 4–6 minutes at a temperature of 101-106 °C. Zucchini were blanched with hot water (85–95 °C) for 3–5 min with preliminary exposure in a 10 % solution of sodium chloride (NaCl) at a temperature of 25 °C for 20 min. And carrots were boiled for 3 minutes in boiling water to soften the structure. Chopped vegetable raw materials, after undergoing additional operations of preliminary heat treatment, were sent for drying in an IR field under the conditions of low-temperature processing (not higher than 50 °C to a dry matter content (DS) of 5...8 %) [22]. The proposed hardware-technological solutions make it possible to preserve the natural properties and PFIs as much as possible for further use in various recipes of food products, in particular, meat and vegetable products with further low-temperature processing in the designed model of the rotary apparatus.

The preparation of minced meat and vegetables was implemented using the example of meat loaf according to the recipe ratio (not salty raw materials): pork meat (16.5 per 100 kg), chicken (39 per 100 kg). Multicomponent dried semi-finished product based on potatoes, Jerusalem artichoke, zucchini, and carrots (ratio of components 1:1) – 3.0 kg per 100 kg. Salt (1.35 kg per 100 kg). Recipe ingredients were mixed [23] with subsequent loading of trolleys with geometrically variable forms or functionally closed environments depending on technological needs. After that, an auxiliary technological operation was implemented to install a needle thermocouple in the center of the loaf with further low-temperature processing until reaching 80 °C in the center of the product. The finished meat and vegetable product was unloaded from the device and entered for further technological implementation. As a control of the experimental batch of meat-vegetable loaves, a traditional product of meat loaves from the trade network "Meat Master" was chosen. In the course of approbation of the designed rotary apparatus under low-temperature processing conditions, on the example of a meat-vegetable bread, comparative data of the experimental sample with the addition of a multicomponent vegetable dried semi-finished product to the recipe and the control sample were obtained.

Experimental and practical research, including the determination of technological and chemical indicators, had a five-fold repeatability with a relative error of no more than 3 % in accordance with traditional procedures for processing experimental and practical data.

5. Design of a universal rotary device for low-temperature processing of meat and vegetable products under conditions of a competitive mechanism

5. 1. Construction of an experimental model of a universal rotary device for low-temperature processing of meat and vegetable products

The improvement of the equipment and technological process for the production of high-quality meat and vegetable semi-finished products with a high degree of readiness is aimed at the formation of resource efficiency through the following:

– construction of a universally optimal working chamber for low-temperature processing of meat and vegetable products;

– ensuring a uniform temperature field with a rational technology for the location of heat-generating elements, which, in turn, eliminates the need to use intermediate high-temperature heat carriers, technical networks and reduces the overall energy and metal consumption of the equipment;

– technical solutions aimed at the formation of functional structural and technological containers for meat and vegetable products in and without a casing;

– technical solutions aimed at converting secondary thermal energy into low-voltage power supply for production needs to ensure convection in the working chamber of the universal apparatus;

– technological solutions aimed at increasing the functionality of meat products by adding vegetable semi-finished products of a high degree of readiness to their recipes.

The designed model of a universal rotary device for low-temperature processing of meat and vegetable products (Fig. 1, *a*) has a cylindrical working surface 1. Structurally, the inner surface of the working chamber 1 is a repeating cylindrical geometry of a film-like resistive electric heater of the radiating type (FlREhRt, 2 [24]), which is externally covered for frame strength with thin-sheet heat-insulating alufoam with metal lining 3. Inside the cylindrical chamber 1, a frameless drum 4 with quick-disconnect mechanisms 5, to which trolleys with processing containers 6 for meat and vegetable products in a shell are attached, rotates inside the cylindrical chamber 1, and without it.

The side walls of the cylindrical working surface 1 for structural and technological maintenance have one stationary wall 7 and a technical wall 8 with the possibility of opening to an angle of 90° due to movable hinges 9. On the inner surfaces of the side walls (7 and 8, Fig. 1, *b, c*), there is FlREhRt additionally installed on inclined converging ribs 10 with an angle of 25° (2), ensuring the uniformity of the distribution of the radiant heat flow. The proposed geometrical arrangement will make it possible to form the effect of cross propagation of IR waves from FlREhRt (2),

which is especially relevant under the conditions of rotation inside the cylindrical working chamber 1 without the frame drum 4.

For the convenience of loading and unloading of structural and technological containers with functional properties, the universal rotary device of continuous action on the stationary wall 7 has a technical opening door 11. Structurally, the door 11 is an opening of two vertical halves of a rectangular shape, to which a technical surface for the placement of trolleys is attached in the lower part 6, allowing us to implement the processes of unloading and loading the device.

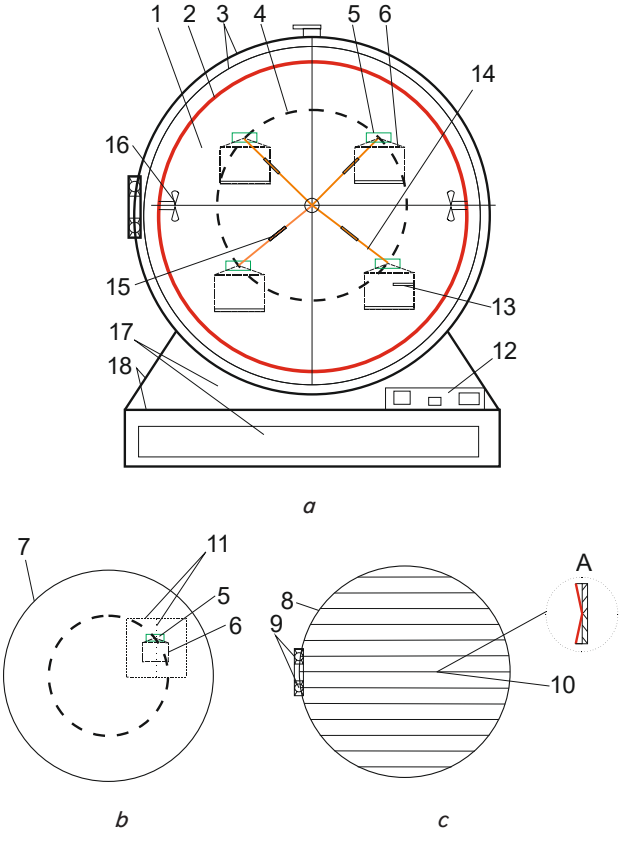

Fig. 1. Diagram of the designed model of the universal rotary device of continuous action for low-temperature processing of meat and vegetable products: *a* — general view; *b* — stationary wall (7) of the apparatus with loading and unloading doors — 11 (inclined converging ribs 10 are not shown in the diagram); *c* — the technical wall (8) of the apparatus with the possibility of opening at 90° with a schematic representation of inclined converging ribs 10 with an inclination angle of 25° covered with FlREhRt (2): 1 — the cylindrical working surface of the apparatus; 2 — a film-like resistive electric heater of the radiating type (FlREhRt); 3 — thin-sheet heat-insulating aluminum foil with metal cladding; 4 — drum without frame; 5 — quick disconnect mechanisms; 6 — carts with technological containers (in the lower part there are juice collectors); 7 — stationary wall; 8 — technical wall; 9 — movable joints; 10 — inclined converging ribs; 11 — folding door; 12 — control units; 13 — needle thermocouples; 14 — strength ribs; 15 — Peltier elements; 16 — autonomous fans; 17 — smoke generator with technical lines; 18 — fixing platform of the device

In order to implement low-temperature processing of meat and vegetable products in the shell and without it, in accordance with the structural solutions, trolleys with technological containers 6 were modeled to improve the functional properties of the device. Frameless trolleys (with hooks for horizontal arrangement of products in various casings (cellulose, etc.), located in functionally closed environments and horizontal shelves for arrangement in geometrically variable forms) for the possibility of receiving meat products with original forms.

Loaded carts (6) with meat and vegetable semi-finished products are moved to the inner space of the cylindrical working chamber 1 with the help of a loading and feeding stick and are fixed on quick-detachable mechanisms 5, fixed on a frameless drum 4. After loading, the operator closes door 11, the low-temperature mode of heat and mass transfer processing is selected on the control unit 12 (technical properties of FlREhRt provide a temperature range from 10 °C to 120 °C on the radiating surface). The temperature control in the device is carried out by needle thermocouples 13, the technical networks of which are located in the frame of functional carriages 6, strength ribs 14 without a frame drum 4 with further connection to the control unit 12. The control unit 12 makes it possible to control the low-temperature process via the multi-channel thermostat from the company "OVEN" (Ukraine, Kharkiv), the frequency of rotation of the frameless drum 4. Adjust the low-voltage supply voltage coming from the Peltier elements 15 to the autonomous fans 16.

To confirm the effectiveness of the proposed universally optimal working chamber of the rotary device under the conditions of the location of FlREhRt on the inner surface of the working chamber 1 and the side walls 6 and 7, the temperature fields were determined. For this purpose, a cylindrical ring ($1^{/}$) with isolated thermocouple contacts (Fig. 2) was additionally attached to the frameless drum 4, which were connected to the control unit for fixing the temperature field in real time. In addition, in Fig. 3, thermocouple $2^{/}$ was responsible for measuring the temperature range of time in the meat delicacy.

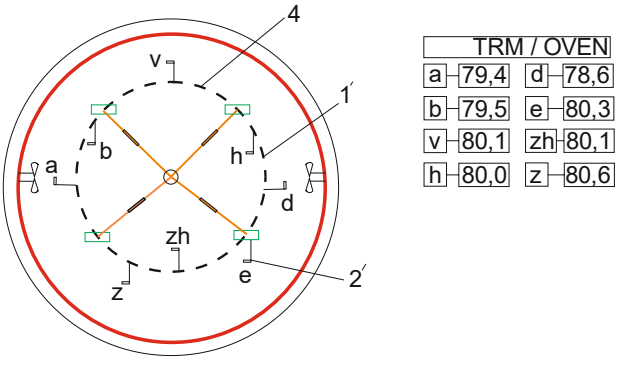

Fig. 2. Layout of thermocouples in the universal rotary device of continuous action for low-temperature processing of meat and vegetable products: 4 — frameless drum; $1^{/}$ — cylindrical ring with needle thermocouples (a....z); $2^{/}$ — a needle thermocouple in a meat delicacy

Analysis of the temperature field confirms the uniformity of the temperature field, slight deviations on the needle thermocouples: a and d can be explained by the operation of autonomous fans 16. On other thermocouples in real time, a small discrepancy of the temperature indicators is

established, which is explained by the measurement error. In addition, the needle thermocouple – e, inserted into the meat-vegetable delicacy, also recorded the temperature in the center of the loaf at 80.3 °C, which corresponded to the preset on the control unit 12.

The designed model of a universal rotary device for low-temperature processing of meat and vegetable products in order to increase the resource efficiency of the equipment and technological process has a structural possibility of using secondary heat. This is an important component of any modern technological equipment based on heat-generating elements (electrical, intermediate heat carriers, heaters, etc.) and is relevant even for low-temperature technological regimes of heat-mass exchange processing of meat products. For the use of secondary thermal energy during low-temperature processing into technical low-voltage supply voltage for autonomous operation of fans 16, Peltier elements 15 are used, which are located in the strength ribs of the frameless drum 4. The optimal location of Peltier elements makes it possible not to use the usable area of the cylindrical working chamber 1 and does not interfere with the uniformity of distribution heat flow. The low-voltage supply voltage (~3...8 W) generated from the Peltier elements allows the fans to operate autonomously even when reaching 15 °C, creating an additional convective movement of the surface layers in the working chamber.

The proposed model of the universal rotary device for low-temperature processing of meat and vegetable products to expand the functional properties in the lower part has a built-in smoke generator 17 with its technical lines, which is mounted in the fixing platform of the device 18. The rotation without a frame drum 4 is carried out through a speed converter and has an adjustable frequency 0.03...0.06 s^{-1}.

The range of meat products does not have a large share of competitive delicacies and in most cases does not use vegetable semi-finished products with a high degree of readiness in their recipes. The use of natural semi-finished products with a high degree of readiness makes it possible to expand the functionality of meat products, giving them their original natural properties and even replacing a certain percentage of recipe ingredients (bread, meat, etc.). In addition, the use of vegetable semi-finished products allows enterprises to partially and even completely abandon foreign synthetic ingredients (dyes, flavorings, etc.), providing competitive advantages to products and support for their own agro-enterprises. In order to confirm the functionality of the designed model of the universal rotary device for low-temperature processing of meat and vegetable products, studies were additionally conducted on the addition of a vegetable semi-finished product of a high degree of readiness to the recipe of chopped meat semi-finished products.

5. 2. Verifying the effectiveness of engineering solutions during experimental and practical testing

A condition for the development of agro-industry is the complex territorial and sectoral functioning of economic clusters aimed at a qualitative approach from "farm to table". The integration of different sectors of the country creates efficient and innovative agri-food production chains to increase competitiveness in the market by producing products with increased quality, functional and original properties. In the course of the research, an integrated adaptive mechanism (Fig. 3) was proposed, aimed at comprehensive cooperation under the conditions of unification of agrarian, processing, and production sectors for the formation of resource efficiency of production processes to increase productivity and quality of products.

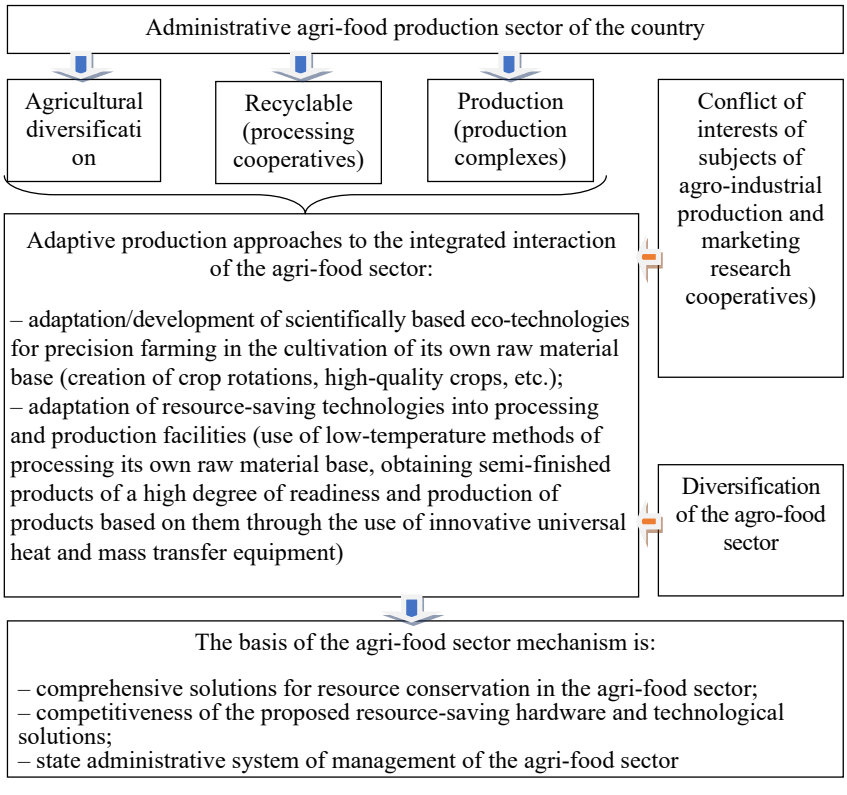

Fig. 3. Integrated adaptive mechanism for the system of complex interaction of agrarian, processing, and production sectors for the formation of resource efficiency of production processes

Adaptive production approaches to the complex interaction of the agro-food sector will make it possible to organize production aimed at diversification, specialization, and concentration of enterprises of various activities in the field of cultivation/processing/production, finance and marketing in other areas.

One of the main areas of diversification of the agro-food sector in terms of adaptive technologies of the agricultural sector, the processing sector and the production sector can be considered:

– concentric – creation of vegetable semi-finished products with a high degree of readiness and food products based on existing or improved technologies under the conditions of using materials (raw materials), basic recipe ingredients and their replacement of synthetic ingredients. The agrarian sec-

tor acts as a fundamental component of growing one's own raw natural base (farmlands, cooperatives, gardens, etc.);

– horizontal – taking into account production needs aimed at changing existing technologies in terms of improvement/adaptation or development of new ones (for the agricultural sector, this is eco-technologies based on precision agriculture). For the processing and production sectors, this is the improvement of technological solutions due to the introduction of resource-saving low-temperature methods and universal mobile heat and mass exchange equipment without the use of high-temperature heat carriers and with secondary energy processing complexes. Preference is given to mobility by locating directly in the places of begging for agricultural raw materials with the subsequent use of low-temperature portable equipment for the production of semi-finished products of a high degree of readiness;

– corporate – re-equipment/creation and production of fundamentally new plant raw materials of own cultivation, obtaining plant semi-finished products of a high degree of readiness (pastes, powders, etc.) and food products of functional purpose. The production sector is the final area responsible for the production of food products with an increased content of PFIs and original organoleptic and rheological properties due to the introduction of natural semi-finished products of a high degree of readiness into the recipes.

The implementation of an integrated adaptive mechanism for the system of complex interaction of the agricultural, processing, and production sectors for the formation of resource efficiency of production processes will have a certain impact on agro-food security and competitiveness, in particular for:

– food security in increasing the production of high-quality and safe food products based on own raw materials, ensuring food security of the population, and reducing the risks of food shortages in war conditions;

– competitiveness will be ensured by the introduction of innovative eco-technologies/low-temperature methods/universal heat and mass exchange equipment and the improvement of the quality of functional products, which will contribute to strengthening Ukraine's position on international markets, increasing export potential, and attracting investments in the agro-food sector;

– resource-saving hardware and technological solutions will be used with stability and adaptability, which will make it possible to quickly adapt processing and production processes to the changing conditions of war, to maintain the stability and efficiency of the agro-food sector.

This approach will contribute to the development of the agro-food sector, increase its resilience and adaptability to modern challenges, and support food security and economic stability of the country, which is especially relevant under the conditions of war and post-war reconstruction.

The introduction of a universal rotary device of continuous action for low-temperature processing of meat and vegetable products with the addition of dried semi-finished products of a high degree of readiness (fruit powders) will make it possible to expand the range of meat products and ensure a stable supply of functional meat and vegetable products with original organoleptic properties (minimization use of synthetic ingredients), reducing dependence on imports. This will improve the quality and safety of food products, increasing the efficiency and innovation of production and strengthen the economic sustainability of the agri-food sector and support the country's food security and competitiveness in the context of a war on the assortment of meat products.

As a result of studies of the effectiveness of the proposed hardware and technological solutions when using the designed mock-up structure of the low-temperature rotary device, data on the frying of meat and vegetable products were obtained (Fig. 4). Frying of the meat-vegetable bread was implemented under the conditions of low-temperature processing and reaching 80 °C in the center of the product, which was measured by a needle thermocouple connected to the thermoregulator "TPM-450" (Fig. 2, thermocouple – e).

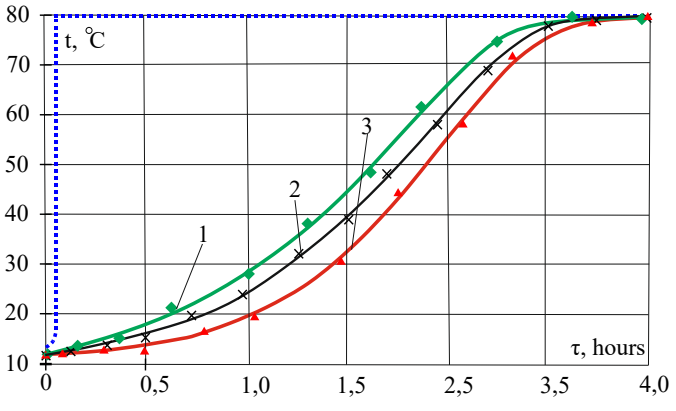

Fig. 4. The process of frying a meat-vegetable product with the determination of the temperature on the surface, in the middle, and in the center of the test sample: — — — duration of the FIREhRt reaching the working temperature (80 °C); 1 — surface temperature; 2 — temperature in the middle layer; 3 — temperature in the center of the test product (thermocouple e, Fig. 3)

The obtained data confirm the practical implementation of the uniformity of the temperature field when frying a meat-vegetable product using the example of bread in a molded form. The nature of raw material heating (initial appearance of geometric curves) followed by gradual transfer of temperature to the inner layers corresponds to the classical understanding of the implementation of the frying process. A certain slight discrepancy in the temperature range in the meat-vegetable experimental product is explained by its formation in a geometric shape (total volume 0.09±0.01 m) and is theoretically permissible during low-temperature frying. The overall cooking readiness of the meat-vegetable loaf, provided that the center of the loaf reaches 80 °C, is reached in 4.0 hours during low-temperature processing in the designed model of the rotary apparatus.

Experimental and practical technological and chemical indicators of the meat-vegetable product were also determined (according to selective PFIs, Table 1).

The introduction of a polycomponent dried fraction based on potatoes, Jerusalem artichokes, zucchini, and carrots into the recipe of the meat-vegetable bread makes it possible to reduce the weight loss of the semi-finished product during frying under low-temperature processing conditions by 12.3 %. In addition, the use of dried semi-finished product makes it possible to increase PFIs of the product, in particular calcium, phosphorus, preserves vitamin C, while reducing energy value. Polycomponent dried vegetable semi-finished product with a high degree of readiness due

to its moisture-retaining properties makes it possible to preserve the juiciness of the meat-vegetable product under conditions of low-temperature processing, and therefore is a significant competitor to foreign synthetic ingredients (phosphates, etc.). Therefore, the introduction of multi-component vegetable dried semi-finished products of a high degree of readiness is effective not only in the production technologies of meat and vegetable products. It can be used in other formulations of food products to increase PFIs and obtain products with original organoleptic and rheological properties.

Table 1

Comparative technological and chemical indicators of meat-vegetable bread in comparison with control from the trade network "Meat Master"

Indicator	Meat bread from the retail chain «Meat Master»	Meat and vegetable bread obtained in the developed mock-up design of a low-temperature rotary apparatus
Weight of semi-finished products (g)	650±20	650±20
Weight of finished products (g)	530±20	570±20
Mass loss (%)	18.5±5	12.3±5
Relative shrinkage (%)	17.2±5	–
Duration of heat treatment, sec.	720	450
Total moisture, %	58.2±0.1	68.6±0.1
Carbohydrates (%)	26.8±0.2	13.1±0.5
Polysaccharides:	14.4±0.1	11.8±0.1
– starch	10.4±0.1	2.3±0.1
– fiber	0.32±0.01	2.64±0.03
Ash, %, including:	2.6±0.01	3.7±0.01
– phosphorus (mg/100 g)	728.3±3.0	1238.0±6.0
– calcium (mg/100 g)	276.2±2.0	197.3±0.7
– iron (mg/100 g)	6.32±0.04	1.65±0.03
Fiber, %	0.23±0.01	0.28±0.01
Vitamin C, mg %	–	10.6±0.3
Energy value, kJ	246.0±3	192±3

6. Discussion of effectiveness of the universal low-temperature rotary device for meat and vegetable products

The engineering solution is aimed at forming a universally optimal working chamber for low-temperature processing under conditions of uniform heat flow distribution and the use of secondary heat energy in the production of a wide range of meat and vegetable products.

The designed experimental model of the universal rotary device for low-temperature processing of meat and vegetable products (Fig. 1) is a cylindrical chamber with an internal coating of FlREhRt, and on the outside – for frame strength, thin-sheet heat-insulating alufoam with a metal lining. A frameless drum with quick-disconnect mechanisms rotates inside the chamber, to which trolleys with processing containers for meat and vegetable products are attached. Side walls: stationary with technical sliding doors for loading-unloading and technical that opens at an angle of 90°, while on the inner surfaces of the side walls additionally installed on inclined converging ribs with an angle of 25° FlREhRt for uniform distribution of the heat flow. For the possibility of simultaneous heat treatment of a diverse assortment, the device has frameless trolleys (with hooks for the horizontal arrangement of products in various casings (cellulose, etc.), located functionally closed environments and horizontal shelves for the arrangement of geometrically variable shapes) for the possibility of receiving meat products with original forms. The use of FlREhRt provides a temperature range from 10 °C to 120 °C on the radiating surface. The speed of rotation without a frame drum has an adjustable frequency of 0.03...0.06 s^{-1}.

The effectiveness of the geometry of the universally optimal working chamber of the rotary device with the proposed location of FlREhRt on the inner surface of the working chamber and the side walls (Fig. 1, items 1, 6, and 7) was confirmed by determining the temperature fields (Fig. 2). Results of thermocouple values in real time confirm the uniformity of the temperature field (deviation of the values of thermocouples: a and d, explained by the operation of autonomous fans). For the use of secondary thermal energy during low-temperature processing into technical low-voltage power supply voltage (~3...8 W) for autonomous operation of fans, Peltier elements were used – located in strength ribs without a frame drum.

We have proposed integrated adaptive mechanism for the system of complex interaction of agrarian, processing, and production sectors for the formation of resource efficiency of production processes (Fig. 3). Its features are:

– cultivation of vegetable raw materials using eco-technologies based on precision agriculture,

– obtaining semi-finished products with a high degree of readiness using resource-saving technology,

– introduction to the recipes of semi-finished meat products under the conditions of further heat and mass exchange processing on a universal rotary device of continuous action with low-temperature processing of meat and vegetable products.

In the course of approbation of the device, data were obtained on the frying of meat-vegetable bread under the conditions of low-temperature processing and reaching 80 °C in the center of the product, which was measured by a needle thermocouple connected to the thermoregulator "TPM-450" (Fig. 2, 4, thermocouple – e). The overall cooking readiness of the meat-vegetable loaf, provided that the center of the loaf reaches 80 °C, is reached in 4.0 hours. The introduction of a multicomponent dried fraction based on potatoes, Jerusalem artichokes, zucchini, and carrots into the recipe of meat-vegetable bread reduces the weight loss of the semi-finished product during frying under low-temperature processing conditions by 12.3 % (Table 1). An increase in calcium and phosphorus is also provided, vitamin C is stored, and the energy value decreases. Traditional designs of rotary devices have high-temperature steam jackets with uneven temperature distribution and limited functionality for the received meat products, which led to a decrease in resource efficiency of the technology. The difference of the proposed resource-saving hardware and technological solution from traditional technologies is the low-temperature processing of meat and vegetable products under the conditions of uniform heat supply, the use of secondary heat energy, and the possibility of obtaining a wide range of functional products [25].

Limitations of the research in the production of meat and vegetable products with multicomponent dried semi-finished products of a high degree of readiness included in the recipes require taking into account the heat-labile and functional properties of plant raw materials, in order to comply with daily consumption norms. Failure to comply with the proposed hardware and technological solutions will lead to a decrease in the competitive properties of meat and vegetable products and a decrease in the resource efficiency of the technology. One of the shortcomings of our research is the lack of generalized data on the implementation of resource-saving low-temperature processing of meat and vegetable products. Further research will be aimed at forming a generalized experimental and practical base for resource-saving low-temperature processing of meat and vegetable products.

7. Conclusions

1. An experimental model of a universal rotary device of continuous action for low-temperature processing of meat and vegetable products has been designed. A feature is the repetition of the cylindrical geometry of the working chamber with a film-like resistive electric heater of the radiating type. The apparatus has a stationary wall (with a technical door for unloading and loading the apparatus) and a technical one (with an opening angle of 90°). On the inner surfaces of the side walls, inclined converging ribs with an angle of 25°, which are covered with a film-like electronic heater, are additionally installed. Meat and vegetable semi-finished products are loaded into the device on carts with technological containers (with hooks for products in shells; functionally closed environments; horizontal shelves with geometrically variable shapes) and are mounted on a frameless drum with a rotation frequency of 0.03...0.06 s^{-1}.

The device has the possibility of using secondary thermal energy during low-temperature processing into technical low-voltage power supply voltage (~3...8 W) for autonomous operation of fans by using Peltier elements located in the strength ribs of the frameless drum. To expand the functional properties, a smoke generator for obtaining smoked meat and vegetable products is built into the lower part of the device.

2. We have proposed an integrated adaptive mechanism for the system of complex interaction of agrarian, processing, and production sectors for the formation of resource efficiency of production processes from "loan to table". During the approbation of hardware and technological solutions implemented in the developed mock-up design of the low-temperature rotary device, the process of frying meat-vegetable bread was implemented under conditions of reaching 80 °C in the center of the product. The obtained data of the temperature field confirm the uniformity of the temperature field when frying the product in the form. The meat-vegetable bread is ready in 4.0 hours with an initial weight of 650±20 g.

The introduction of a multicomponent dried fraction based on potatoes, Jerusalem artichokes, zucchini, and carrots into the recipe of meat-vegetable bread reduces the weight loss of the semi-finished product during frying by 12.3 %. There is an increase in the content of calcium, phosphorus, vitamin C, and other functional ingredients with a simultaneous decrease in energy value by 28.1 %.

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 and the results reported in this paper.

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Data availability

All data are available 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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