The object of this study is the production process of chopped meat semi-finished products with the addition of blended dried semi-finished products based on Jerusalem artichoke, pumpkin, and zucchini to the recipe, followed by frying in functionally closed environments.

A technique for the production of dried semi-finished products based on Jerusalem artichoke, pumpkin, and zucchini is proposed for use in the recipes of fried minced meat products to substitute bread. The water absorption of bread (at 23 min.) was compared at 11.3 cm^3 and 12 cm^3 for the dried mixture, which is 6.1 % higher. A comparative analysis of the chemical composition confirms a much higher content in the dried blend: 6 times more potassium, 4 times more calcium, and 31 times more dietary fiber. Also, the blend is characterized by a low fat content of 0.13 g and the presence of vitamins C, A, etc.

Frying of chopped meat semi-finished products is proposed in functionally closed environments (FCE) with artificial cooling based on a heat exchanger with cold water and Peltier elements. The process is carried out at a temperature of 150…160 °C for 300 seconds.

It was found that during 30 s of frying the test samples in FCE, the pressure is equal to $9 \cdot 10^3$ Pa, during 90 s – $28 \cdot 10^3$ Pa, at 120 s – $35 \cdot 10^3$ Pa, at 210 s – $40 \cdot 10^3$ Pa, and at 300 s – $42 \cdot 10^3$ Pa, respectively, which makes it possible to predict the process.

The dynamics of frying chopped meat products in FCE with artificial cooling on the basis of a heat exchanger with cold water and Peltier elements for the 1st period of loss are about $52.6 \cdot 10^{-3}$ %/s, for the 2nd it is virtually unchanged. The maximum difference in changes in the fat medium is on 120…150 seconds of frying and actually reaches 12.0 % of the total fat content. At the end of the frying process, the total content of fatty medium is about 5.3 %, thereby confirming the effectiveness of using artificial cooling

Keywords: functionally closed environments, dried semi-finished products, absorption capacity, fat content

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IMPROVING A TECHNIQUE FOR MAKING FRIED MEAT CHOPPED SEMI-FINISHED PRODUCTS IN FUNCTIONALLY CLOSED ENVIRONMENTS WITH THE ADDITION OF BLENDED DRIED SEMI-FINISHED PRODUCT

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1. Introduction

The living conditions of European countries, ecological situations, and probable intelligence of chronic and pandemic diseases, in accordance with the recommendations of the World Health Organization, require the provision of a daily rational preventive diet without specifying the type of food [1]. In most cases, according to traditional technologies for the production of food products, including meat semi-finished products, in order to simplify and reduce the cost of the technological and equipment component, various synthetic dyes and flavorings are used. According to their physiologically functional (FFI) properties and chemical composition do not form a prophylactic effect in consumers, and therefore have no benefit for consumers. Thus, there is a need to find innovative, competitive hardware and technological solutions to expand the range of products, which, when consumed, will be able to form curative and preventive actions under the conditions of minimizing artificial and synthetic ingredients. One of the sources of FFI of natural origin is the natural raw material base of European countries (fruits, vegetables, berries, etc.), thus, forming a decrease in the dependence of producers on foreign synthetic ingredients [2]. Given the fact that meat products are one of the main meals and have a wide demand due to the use of traditional technological processes, the equipment cannot always provide a rational technological process under the conditions of resource-efficient technologies [3]. The use of technological equipment with resource-efficient technologies based on autonomous properties under gentle temperature regimes will make it possible to preserve the original properties and FFI as much as possible and to obtain everyday food products.

The engineering combination of technological and technical features of the implementation of hardware design

in the production of chopped meat semi-finished products with the addition of blended dried semi-finished products in functionally closed environments is the key to the formation of production competitiveness. Improvement of the method of production of chopped meat semi-finished products with the addition of blended dried semi-finished products in functionally closed environments is, in turn, an actual safety solution for the food component of European countries.

2. Literature review and problem statement

Meat semi-finished products are an assortment of everyday food under the conditions of a traditional assortment, manufactured according to classic technologies with a predicted nutrient composition and the use of synthetic ingredients (colors and flavorings). The introduction of natural ingredients into the recipes of meat products will make it possible to obtain an increased content of physiologically functional ingredients (FFI) with a regulated nutrient composition and original organoleptic properties without a synthetic component [4]. The proposed design of the apparatus for low-temperature processing of meat delicacies is based on a flexible electronic heater with uniform temperature distribution, provided that 71...75 °C is reached in the center of the product. However, the disadvantage of the proposed solution is the lack of structural solutions aimed at *min*imizing the mass loss of test samples during heat treatment. This may be related to the peculiarity of the design of the device, which in turn confirms the relevance of research into this area. Work [5] confirms the expediency of using natural raw materials in the obtained food products for daily consumption, thereby creating competitive nutritional products for medical and preventive purposes. In addition, this technological approach forms in the consumer the habit of rational nutrition and the demand for meat semi-finished products of natural origin. In most cases, plant raw materials are not suitable for use in food recipes in their pure form, due to rapid spoilage, difficulty of long-term storage, etc., leading to the introduction of innovative ways of processing them. One of the promising solutions is the production of dried semi-finished products under the conditions of using gentle temperature ranges for the maximum preservation of biological value under the conditions of using own raw material bases. In work [6], ways of informing consumers about the need for a rational diet are given using the example of meat, however, the possibility of increasing the nutrient composition due to the use of natural ingredients in different forms (chopped, paste-like, dried, etc.) remains to be noted. One of the solutions for the production of natural semi-finished products with a high degree of readiness is given in [7], however, due to the incompleteness of research, it is not possible to determine the relevance of use directly in the meat industry. This predetermines the relevance of research on determining the possibility of using natural ingredients in a comprehensive study not only of technological parameters, but also of hardware and resource-efficient features of the implementation of the process of frying semi-finished meat cuts. In particular, work [8] focuses attention on hardware and technological shortcomings (high temperature, metal and energy consumption, uneven heat supply, etc.) and their impact on the quality of processing of natural raw materials, emphasizing the feasibility of implementing engineering hardware solutions. Thus, a study of the relationship between the system of automatic evaluation of meat products and the advantages and needs of consumer cooperation was carried out. But practical approbation of the competitiveness of the obtained meat products is impossible in real *time* without taking into account the peculiarities of the use of the equipment and technological component. This is due to the variety of hardware and technological solutions, conditions for their implementation and features, including prescription ones, focusing on the need to conduct comprehensive research during the implementation of innovative solutions on the resulting competitiveness of the product.

Paper [9] notes the need for a rational approach to the selection of plant raw materials with a significant content of nutrients and original properties for the formation of a blend that will meet the daily consumption standards. This, in turn, is a difficult task, as it needs to be specified in which product natural raw materials will be used, and which stages of heat and mass exchange operations will take place, since valuable components are quickly lost from high temperatures. So, for example, in [10], a complex solution for the processing of vegetable raw materials into dried semi-finished products of a high degree of readiness in conditions of uniform heat supply is considered. However, there are questions about the justification of blending because a semi-finished product should be obtained, and it needs to be adapted to the further technological process. It is necessary to determine the water-absorbing and rheological properties for the formation of the dynamics of mass and moisture loss and the degree of increase in nutrients, thereby emphasizing the relevance of research into this area. For example, the use of vegetable raw materials with a high content of nutrients, in particular: Jerusalem artichoke, zucchini, pumpkins, beets, apples, etc., will make it possible to form antioxidant, immunostimulating properties in the finished product. And also, curative and preventive properties in general, which is relevant for rational nutrition in order to support the immune component of consumers. It has been proven [8] that the nutrient components of Jerusalem artichoke, pumpkin, and zucchini contain inulin, which is a natural functional dietary fiber, contains pectin-containing substances, and is characterized by high water-absorbing properties in dried form. In addition, consumer interest in consuming inulin due to its low calorie content increases the demand for food products based on it. However, issues related to the determination of rational ratios of dried semi-finished products of a high degree of readiness depending on the recipes of the future product and the specifics of the hardware and technological implementation remained on the sidelines. This is due to the complexity of practical testing, both at the hardware and technological level, and at the obtained quality properties, as it requires large-scale experimental and practical research, which must be implemented during the implementation of innovative solutions.

Paper [11] presents an automatic system for evaluating the quality of rational consumption based on formed consumer needs and nutrient composition. However, in the context of the consumption of chopped meat products, it is not possible to fully use this technique, which is connected with a significant range of products and not all segments of the population can afford quality products. This requires the search for competitive solutions that will be based on the combination of gentle and rational modes of processing not only the vegetable component but also the meat product as a whole in terms of resource efficiency. Creating an expansion

of the available range of food products with adjustable nutrient composition, and therefore the feasibility of research into this area is confirmed. One of the solutions is given in work [4], where meat raw materials are produced under conditions of gentle IR radiation and low temperatures, ensuring maximum preservation of initial properties, in particular juiciness. However, the shortcoming of the research is the narrow specialization of the apparatus for obtaining meat delicacies, and to expand the range of products, it is necessary to form thermal apparatuses that are more widespread in terms of the forms of working chambers. Traditionally, the amount of the working chamber is kept on the received assortment, this in turn determines the search for rational geometric chambers for the assortment of meat products with wide demand (sliced semi-finished products, sausage products, etc.). Thus, in [12], heat and mass transfer with subsequent changes in the physical properties of pork during deep-frying was determined. Frying was carried out in the range of 90...110 °C, and the moisture diffusion coefficient varied from 1.5 to $30.2 \cdot 10^{-9}$ m^2/s, the convective heat transfer coefficient – from 187.7 to 226.1 $W/m^{2} \cdot °C$. A significant influence on the density, color, and texture of the crust of the frying temperature was established, but the effect of the properties of the frying surface and the fact that the frying took place in an open air environment were not taken into account. The engineering decision to carry out research on frying under the conditions of the formation of overpressure, which can change the nature of the technological process and requires detailed research into this area, was neglected. One of the solutions was implemented in work [9] on the determination of heat and mass transfer during frying of cut meat semi-finished products with direct contact with the heating surface for 4 min. It was established that the heat flow as a function of time depends on the physical and chemical properties of the meat product during frying and the temperature of the heating surface. However, the method of heat supply and the formation of its uniformity is not specified in the work, which significantly affects the heating rate, in particular of the central layers of the test samples and requires the implementation of an intermediate operation of turning over. In work [13], the implementation of the frying process in sealed environments is considered as one of the solutions for reducing mass losses, however, comprehensive studies of the possibility of using natural raw materials and frying in sealed chambers remain undefined.

In work [14], the technology of heat treatment based on hydrostatic pressure – "sous-vide" was investigated using the example of meatballs. The influence on the physical and chemical characteristics of veal, vegetable, and hybrid cutlets was determined. Samples of different compositions were exposed to three pressures (350...600 MPa) for 5...15 min with "sous-vide" (55...65 °C for 15 min). The color of the plant-based and hybrid treated cakes tended to be less reddish and more yellow. The cutlets were similar to the veal cutlets in terms of color and texture parameters, while the physicochemical parameters of the plant-based cutlets differed from the veal cutlets. In work [12], the reduction of losses of chopped meat products with natural nutrients in traditional technology was investigated using oats as an example. But the advantages of a complex solution are not fully covered, namely the advantages of using natural raw materials, the influence of water absorption capacity and the method of heating the working chamber. It is the implementation of a complex study to determine the nutritional advantages of plant raw materials, blending methods, obtained absorption capacities and chemical composition under the conditions of determining dynamic properties during frying in functionally closed environments. It is the main task to obtain a competitive hardware and technological solution under the conditions of using innovative equipment and methods of production of chopped meat semi-finished products with a natural nutrient composition. This is especially relevant for hotel-restaurant-type enterprises, medium and small businesses, as they can provide the consumer with not only semi-finished products but also ready-made meat products, thereby forming a rational diet. For large enterprises, in most cases, various mixers are used for blending and mixing of recipe components, the performance of which depends on the volume of products produced in a certain period of time [15].

The above creates the need for comprehensive research aimed at the rational selection of plant raw materials with their subsequent processing under conditions of gentle heat and mass exchange operations. First, the determination of the obtained absorption capacity depending on the final moisture content, which will make it possible to make an effective decision to replace certain recipe components with a blended semi-finished product, or to use it as an additive. For this, it is necessary to take into account the comparative analysis of the recipe components and the selected blended semi-finished product since this will lead to changes in the rheological properties (degree of swelling and moisture absorption) under the conditions of replacement or addition of recipe ingredients. The second component of the complex solution is the use of engineering solutions to ensure the uniformity of heat supply, the use of secondary energy, the reduction of mass losses, and the formation of original organoleptic properties due to natural nutrients and preserving the juiciness of products. This leads to the need to conduct experimental and practical research for the formation of the above-mentioned competitive advantages for the production of original chopped meat semi-finished products with introduced natural "health and preventive" nutrients.

3. The aim and objectives of the study

The aim of our research is to improve the production process of chopped meat semi-finished products with the introduction of blended dried semi-finished products based on Jerusalem artichoke, pumpkin, and zucchini into the recipe, followed by frying in functionally closed environments. The implementation of the equipment and technological solution will make it possible to obtain original chopped meat semi-finished products with an enriched nutrient composition.

To achieve the goal, the following tasks were set:

– to devise a technique for producing blended dried semi-finished products based on Jerusalem artichoke, pumpkin, and zucchini for further use in the recipes of fried chopped meat semi-finished products;

– to investigate the process of mass transfer during frying of chopped meat semi-finished products in functionally closed environments.

4. The study materials and methods

The object of this study is the production process of chopped meat semi-finished products with the addition of

blended dried semi-finished products based on Jerusalem artichoke, pumpkin, and zucchini to the recipe, followed by frying in functionally closed environments.

The main hypothesis of the research assumes the possibility of improving the method of production of fried chopped meat semi-finished products with the addition of blended dried semi-finished products based on Jerusalem artichoke, pumpkin, zucchini under the conditions of using competitive equipment and technological solutions. Forming the expansion of chopped meat semi-finished products with an increased content of FFI.

The research was carried out at the laboratory of the State Biotechnology University (Kharkiv, Ukraine). The object of the research is an improved method of producing fried chopped meat semi-finished products in functionally closed environments with the addition of blended dried semi-finished product based on Jerusalem artichoke (*Skorospilka* variety), pumpkin (*Ilya Muromets* variety), and zucchini (*Skvorusha* variety). The raw material is characterized by a significant content of natural nutrients necessary in the daily diet and has moisture-retaining properties.

Physiologically functional nutrients of the selected natural raw materials sold in the Kharkiv oblast, according to varieties, are taken from literary sources (Table 1, [16–19]).

Table 1

Physiologically functional nutrients of natural raw materials for obtaining blended dried semi-finished products for further introduction into the recipe of chopped meat semi-finished products [16–19]

Physiologically functional ingredients	Raw materials (100 gr.)		
	Artichoke	Pumpkin	Zucchini
Vitamin A, μg	2.3	1.6	0.87
Vitamin B_1, mg	0.63	0.05	0.29
Vitamin B_2, mg	0.05	0.06	0.27
Vitamin B_9, mcg	17.5	14.2	16.0
Vitamin PP, mg	1.9	0.6	0.8
Vitamin C, mg	6.7	8.3	15.7
Phosphorus, mg	81.3	25.0	14.0
Calcium, mg	16.2	24.2	10.0
Potassium, mg	41.0	23.7	30.0
Mono- and disaccharides, mg	3.8	4.2	5.6
Dietary fibers, g	5.5	2.3	1.7
Organic acids, g	0.09	0.1	0.2
Calorie content, kcal	60.0	20.1	21.4

Blending of fruits was carried out according to the previously suggested ratio of components (artichoke – 35 g, pumpkin – 35 g, zucchini – 30 g) according to the principle technological scheme of the production of dried semi-finished products based on gentle production temperature regimes (Fig. 2).

The frying process was implemented on an experimental model of the device for frying chopped meat semi-finished products with functionally closed environments (Fig. 1).

The device is two cylindrical platforms in the form of a protective casing (body) (1) on which 16 functionally closed environments (FCE, 2) are placed. To provide artificial cooling of FCE, a tubular heat exchanger (3) is placed on the main platform. The location of the tubular heat exchanger in the form of covering waves of FCE increases the cooling contact area, and in the absence of a cooling liquid (water), it acts as an additional heat insulator with the air medium. The fluid injection/discharge pipe (5) from the tubular heat exchanger is connected to the flow meter located on the control unit (8) and the main line. The working surface of the device is heated by a film-like resistive electric heater of the radiating type (FlREhRt, 7) provided that the cylindrical surfaces (1) are connected by means of a hinge mechanism (9) and a locking handle (6). Under these conditions, a functionally closed environment is created (2).

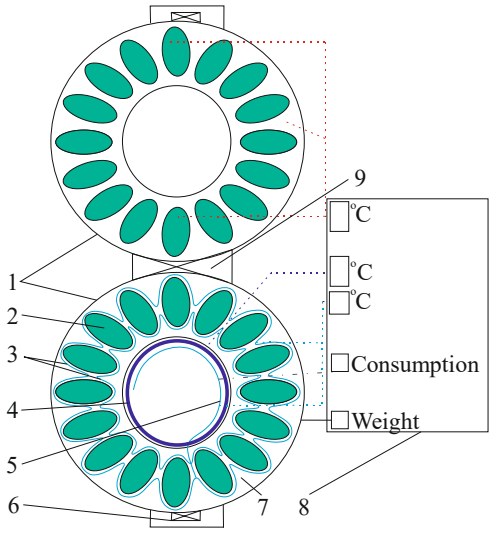

Fig. 1. Schematic of an experimental model of an apparatus for frying chopped meat semi-finished products with functionally closed environments and artificial cooling based on a heat exchanger with cold water and Peltier elements (section of the opened apparatus at the level of 10 mm from the surface): 1 – body; 2 – functionally closed environments; 3 – tubular heat exchanger; 4 – a ring of Peltier elements; 5 – liquid injection/drainage pipeline from the tubular heat exchanger; 6 – locking handle; 7 – a film-like resistive electric heater of the radiating type (FlREhRt); 8 – block of automatic control of technical operations; 9 – hinged mechanism

The operation of the device is as follows: pre-prepared meat raw materials are placed in FCE (2) and the cylindrical platforms (1) are hermetically connected with the hinge mechanism (9) and the handle (6). Current (220 W) is supplied to FlREhRt (7), providing heating under the conditions of convective-infrared heat supply. As the temperature increases in FCE, excess pressure and an intensive process of heat and mass exchange with the duration of the frying process (300 seconds) begin to form, after which the FlREhRt is turned off. Cold water is supplied through the liquid injection/flow pipeline (5) connected to the tubular heat exchanger (3), cooling the FCE (2) and the cylindrical platforms (1) as a whole. Thus, ensuring the condensation of the wet-fatty medium and during opening, its partial absorption by the finished product. In turn, the device has a ring of Peltier elements (4), which due to their properties in the process of frying (150...190 °C) create –3...–6 °C on their cold surface. Autonomously reducing the temperature of the coolant to 10 °C without additional consumption of electrical energy.

The automatic control unit of the frying apparatus based on the regulators of the company "Oven" (Kharkiv, Ukraine)

allows you to control the temperature: FCE, on the cylindrical platform, the heat exchanger, the liquid injection/drainage pipeline, and Peltier elements. It also allows you to measure the flow of coolant and measure the change in mass due to strain gauges placed under the cylindrical platform.

During experimental and practical studies, standard procedures for processing the obtained data were used. Including the determination of chemical components, moisture absorption capacity, mass loss and changes in moisture content and had a fivefold repeatability with a relative error of no more than 3 %.

5. Results of improving the production process of chopped meat semi-finished products with the addition of blended dried semi-finished products

5. 1. Devising a technique for the production of mixed dried semi-finished products and the production of fried chopped meat semi-finished products

Blending of fruit raw materials will make it possible to obtain original organoleptic and structural-mechanical properties of the blend, which will make it possible to replace certain recipe raw materials of chopped semi-finished meat, to minimize the use of synthetic flavorings and dyes. Production of dried blend includes the following preparatory traditional operations (washing, inspection, cutting). Preliminary heat and mass transfer treatment by blanching: Jerusalem artichoke (with hot steam 104...108 °C, for 3–6 min.), pumpkin and zucchini – with water (90...97 °C), for 3...8 min., respectively. After that, the raw materials were sent for wiping to a double wiping machine (in stages) with subsequent short-term storage in dispensers. From the dispensers, puree-like raw materials were mixed (under conditions of equal percentage ratio of components) and pumped to the rotary-film apparatus (RPA), where it was pre-boiled at a temperature of 55...60 °C for 0.85...0.9 min. A paste-like mass with a content of 25...30 % DM (dry matter) enters the final technological stage – drying in an IR field in a roller dryer at a temperature of 50...60 °C and a raw material layer thickness of 0.05 mm, to a final moisture content of 3...6 % DM.

The obtained blended dried fruit semi-finished products are further packaged in light-proof polyethylene containers with the use for technological purpose in the recipes of meat semi-finished products and the possibility of sale in the retail network.

Studies have been carried out to determine the possibility of adding blended dried semi-finished products to the recipe of fried meat semi-finished products. In traditional technologies, bread plays the role of an absorbent component of the water-fat medium, and its partial replacement or addition to the recipe of the dried mixture will increase the absorbent properties and increase FFI. The water-absorbing capacity of bread of the 1st grade and blended dried semi-finished product based on Jerusalem artichoke, pumpkin, and zucchini was determined (Fig. 2).

Water absorption of bread of the 1st grade for 5 minutes has a volume of 6.1 cm^3, and the blended dried semi-finished product has a volume of 6.5 cm^3 for the same duration. The maximum water-absorbing capacity for bread of the 1st grade is 11.3 cm^3 at 23 min., and for blended dried semi-finished products – 12 cm^3, respectively. The water absorption capacity of the blended dried semi-finished product is 6.1 % higher.

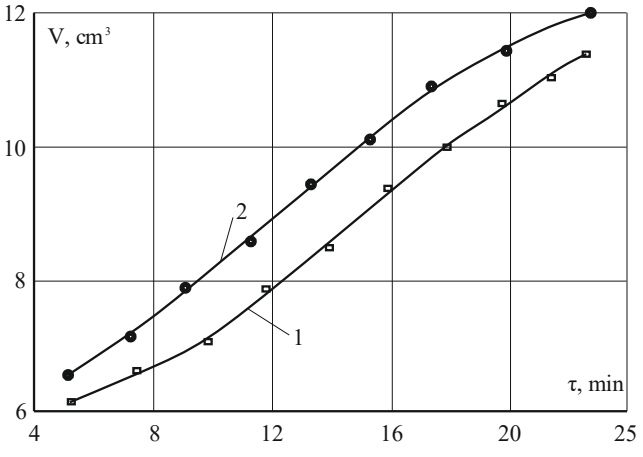

Fig. 2. Moisture absorption capacity: 1 — bread of the 1st grade; 2 — blended dried semi-finished product based on Jerusalem artichoke, pumpkin, and zucchini

A comparative analysis of the chemical composition of bread of the 1st grade with blended dried semi-finished product based on Jerusalem artichoke, pumpkin, and zucchini was carried out (Table 2).

Table 2

Chemical composition of bread of the 1st grade and blended dried semi-finished products

Indicator	Bread of the first grade	Blended dried semi-finished product
Fat, g	1.2±0.1	0.13±0.4
Carbohydrates, g	78.6±0.2	6.32±0.5
Potassium, mg %	147.5±2.0	764.4±0.7
Vitamin, A μg %	0	2.6±0.3
Calcium, mg %	33.1±2.0	350.1±0.1
Carotene	0	20.6±0.3
Vitamin C, mg	0	15.8±0.3
Dietary fiber	2.3±2.0	72.3±2.0

The obtained indicators confirm the effectiveness of using blended dried semi-finished products based on Jerusalem artichoke, pumpkin, and zucchini in comparison with bread. There is 6 times more potassium, 4 times more calcium, and 31 times more dietary fiber. In addition, the bread does not have vitamins C and A, and the blend is characterized by a minimum fat value of 0.13 g.

The technological process of the production of fried chopped meat semi-finished products in FCE with the addition of blended dried semi-finished products consists of the traditional preparatory stages of raw materials, recipe formulation, forming and frying in the proposed apparatus. In particular, the components of minced meat have a ratio, wt. %: beef – 44; pork – 23; wheat bread – 9; water or milk – 16; blended dried semi-finished product – 8. The traditional technology for the production of chopped meat products does not include dried blended semi-finished product and breadcrumbs are additionally used. Implementation of the technology in an experimental model of an apparatus for frying chopped meat semi-finished products with functionally closed environments (Fig. 1) allows the process to be implemented without prior freezing of semi-finished products or after their thawing. Namely, pre-prepared meat raw materials (beef, pork), cleaned of sinews, are sent for uniform grind-

ing in a hopper with an initial size of 2.5...3.0·10^{-3} m. After that, the process of mixing the received soft fraction with recipe components is implemented: blended dried semi-finished product, bread, salt, and spices for 150...250 seconds, at a temperature of 12...16 °C with subsequent molding of the product. Formed products are placed in the internal space of FCE and the frying process is carried out at a temperature of 150...160 °C for 300 seconds. After that, the heating element is turned off and artificial cooling based on a heat exchanger with cold water and Peltier elements begins to be implemented. Frying chopped meat semi-finished products in FCE leads to an increase in the pressure in the cell, preventing intensive evaporation of the water-fat fraction into the environment. The use of artificial cooling of FCE makes it possible to condense the steam formed during the frying process in the product after depressurization of the device. The introduction of a combination of dried and partially replaced bread into the recipe of chopped meat products, in addition to increasing the moisture absorption capacity, increases the content of FFI in ready-made fried products.

The obtained indicators confirm the effectiveness of using blended dried semi-finished products based on Jerusalem artichoke, pumpkin, and zucchini in comparison with bread. There is 6 times more potassium, 4 times more calcium, and 31 times more dietary fiber. In addition, the bread does not have vitamins C and A, and the blend is characterized by a minimum fat value of 0.13 g. In the future, the obtained results are one of the main directions of research regarding the rational content of blended dried semi-finished products under the condition of partial replacement of bread with it, and not only as a supplement of FFI in the recipe of chopped meat semi-finished products.

5. 2. Study of mass transfer during frying of chopped meat semi-finished products in functionally closed environments

In the traditional frying process, the interaction of the physical-chemical and structural properties of raw materials, methods of heat supply and the number of operational stages form the final properties of the finished meat semi-finished product. It should be noted that a significant temperature difference between the surface for frying and the formed chopped meat products leads to rapid boiling of moist and fat-rich environments in a short period of time during frying. Heating the intermediate and central layers of the product leads to the melting of the fat fraction, as a result of protein denaturation, intensive moisture removal, including through the surface layers, forming a significant loss of mass due to evaporation.

The implementation of the frying process in a functionally closed environment (FCE) artificially creates excessive technical pressure directly in the closed environment, ensuring the boiling of moist and fatty environments directly in the cell. At the same time, the steam component, taking into account the internal pressure, counteracts the hydrodynamic pressure, forming the passage of moisture through the surface layers, as in traditional frying. The artificial formation of technical pressure in a functionally closed environment increases the partial pressure and increases the total pressure in the volume of the product, intensifying the frying process due to the additional effect of water vapor. Taking into account that the total duration of the acquisition of the experimental sample of culinary readiness is 300 s, according to the traditional technology with 2-stage turning and proofing in a thermal chamber. It was found that during 30 s of frying the test samples in FCE, the pressure is equal to 9·10^3 Pa, during 90 s – 28·10^3 Pa, for 120 s – 35·10^3 Pa, for 210 s – 40·10^3 Pa, and at 300 s – 42·10^3 Pa, respectively. Therefore, the pressure increase in FCE is predictable and depends on the duration of heat treatment, and the pressure is a direct dependence of the obtained temperature in the middle of the sealed environment. When the pressure increases, the rate of vaporization decreases, and therefore, a decrease in the rate of pressure increase is formed. The technical pressure of FCE increases the force of uniform distribution of the test sample in FCE and reduces weight loss in the absence of direct contact of evaporated moisture with the environment. It partially condenses the steam in the test sample during artificial cooling, which in turn increases the functionality of the implementation of the process of frying chopped meat products in FCE under conditions of safe use.

The dynamics of the rate of mass loss of chopped meat products at the stages of frying compared to traditional frying in 2 operations with a step-by-step reversal in time (180 s and 360 s) are pre-established. And also, under the conditions of single-operation frying in FCE with artificial cooling based on a heat exchanger with cold water and Peltier elements and natural cooling of FCE. The analysis of the rate of change in mass loss (Fig. 3) is characterized by the traditional three maximum values characterizing the culinary readiness of chopped meat products during traditional frying.

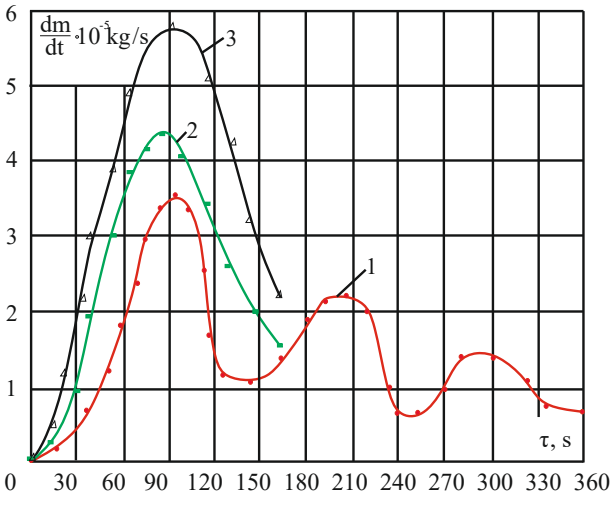

Fig. 3. The dynamics of the rate of change in the mass loss of chopped meat semi-finished products: 1 — control (the sample was obtained by traditional technology); 2 — test samples obtained in a functionally closed environment with natural cooling; 3 — test samples obtained in a functionally closed environment with artificial cooling based on a heat exchanger with cold water and Peltier elements

For control samples in the first period of frying, the maximum heating rate is 3.45·10^{-5} kg/s for 100 s, in the 2nd period – 2.2·10^{-5} kg/s for 200 s, and in the 3rd period, which is responsible for the formation of the sample crust – 1.42·10^{-5} kg/s for 285 s, respectively. The decrease in the heating rate is due to the emergence of resistance to mass transfer of moist and fat-containing environments due to the formation of a crust, thereby reducing the intensity of mass loss. A natural

increase in partial pressure under conditions of rapid contact with a heating surface leads to discontinuous lines of surface layers with intensive removal of moist and fat-bearing environments.

Frying of experimental samples in FCE with artificial cooling based on a heat exchanger with cold water and Peltier elements has the following characteristics of the dynamics of mass changes. In the first period, $5.7 \cdot 10^{-5}$ kg/s for 98 s with a further decrease in the rate of mass loss to $2.15 \cdot 10^{-5}$ kg/s for 165 s under the conditions of the actual achievement of the 2nd period and the formation of a crust. Frying of experimental samples in FCE under the conditions of their natural cooling is characterized by slower mass growth in the first periods for 165 s. The maximum value was reached in 85 s ($4.42 \cdot 10^{-5}$ kg/s) and the minimum value was $1.65 \cdot 10^{-5}$ kg/s.

The change in fat content and the speed of the frying process of chopped meat products in FCE for 180 seconds, under the conditions of natural and artificial cooling based on a heat exchanger with cold water and Peltier elements, were determined (Fig. 4). During natural cooling, initially a slight release of fat-containing medium from the surface layers is observed under conditions of intense heating in the FCE and tight pressing of the sample to the cell. The rate of change in fat content gradually increases in the range of $(15.2...59.6) \cdot 10^{-3}$ %/s, which is actually 2 % of the total rate. After that, the inner layers are heated to the fat melting temperature with an increase in the volume of the fat-containing medium in FCE and an increase in the water vapor pressure. Forming the intensification of the sebaceous secretion process at the level of 3.1 % at the speed of the process of $64.3 \cdot 10^{-3}$ %/s.

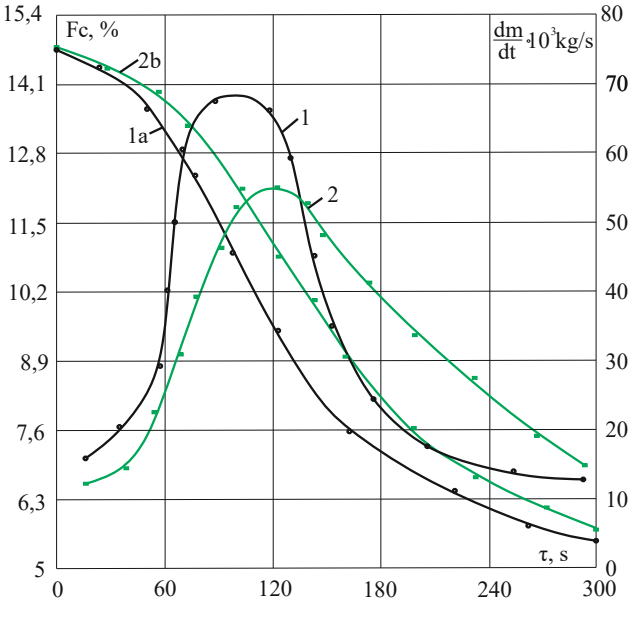

Fig. 4. The dynamics of changes in fat content (Fc) and the speed of frying experimental samples of chopped meat semi-finished products (dm/dτ) in a functionally closed environment: 1b and 1 — natural cooling; 2b and 2 with artificial cooling based on a heat exchanger with cold water and Peltier elements

In the 3rd period, the fat content of the products actually decreases by 4 % with a simultaneous decrease in the speed of the frying process to $13.1 \cdot 10^{-3}$ %/s. Analyzing the data presented on the graph, it is possible to conditionally determine the following duration of the frying periods: the first –75 s, the second – 45 s, and the third – 180 s.

The dynamics of frying chopped meat products in FCE with artificial cooling based on a heat exchanger with cold water and Peltier elements are as follows. In the 1st period of losses, the speed is about $52.6 \cdot 10^{-3}$ %/s, in the 2nd it is virtually unchanged. The maximum difference in changes in the fatty environment is observed after 120...150 s of frying and actually reaches 12.0 % of the total fat content. This can be explained by the fact that the increased pressure of steam condensation inside the products after depressurization of FZM contributes to the removal of fat through their surface, thereby reducing the power of fat transfer. Additionally, periods have the following roast values: 100; 60; and 140 s, respectively. At the end of the frying process, the total content of fatty medium is about 5.3 %, thereby confirming the effectiveness of using artificial cooling.

The analysis of the received experimental data on the dynamics of changes in the mass of chopped meat semi-finished products confirm the feasibility of using FCE with artificial cooling under the conditions of obtaining experimental products.

6. Discussion of results of improving a technique for production of fried chopped meat semi-finished products in a functionally closed environment

A devised technique for the production of mixed dried semi-finished products based on Jerusalem artichoke, pumpkin, and zucchini is proposed under the conditions of preliminary heat and mass exchange treatment by blanching: Jerusalem artichoke with hot steam at 104...108 °C for 3–6 min. Pumpkin and zucchini were blanched with water for 3–8 minutes. at a temperature of 90...97 °C with subsequent wiping on a double wiping machine. The obtained puree-like mass from the dispensers was injected into RPA for preliminary concentration at a temperature of 55...60 °C for 0.85...0.9 min. After that, the paste-like blended mass with a content of 25...30 % DM was dried in an IR field in a roller dryer at a temperature of 50...60 °C and a thickness of the raw material layer of 0.05 mm, to a content of 3...6 % DM.

The possibilities of adding blended dried semi-finished product to the recipe of fried meat chopped semi-finished products were determined under the conditions of comparing the water absorption capacity of bread of the 1st grade and dried blended semi-finished product based on Jerusalem artichoke, pumpkin, and zucchini. Water absorption of I-th bread in 5 minutes is 6.1 cm^3, and for the blended dried semi-finished product – 6.5 cm^3, respectively (Fig. 2). The maximum water absorption capacity for bread of the 1st grade is 11.3 cm^3 in 23 min and 12 cm^3, respectively, for blended dried semi-finished product. Therefore, it is possible to state that the absorption capacity of the dried blend is actually 2.9 % higher, which is explained by the content of 3...6 % DM, the presence of pectin-containing substances, and the minimum content of fat-containing substances, unlike bread. A comparative chemical analysis of FFI of bread of the 1st grade and blended dried semi-finished products was also carried out (Table 2). According to the obtained data, the dried blend has 6 times more potassium, 4 times more calcium, and 31 times more dietary fiber. It is char-

acterized by a low fat content of 0.13 g and the presence of vitamins C, A, etc.

The technological process of the production of fried chopped meat semi-finished products with the introduction of blended dried semi-finished products into the recipe ratio is based on the grinding of meat raw materials ($2.5...3.0 \cdot 10^{-3}$ m) in a grinder with subsequent mixing of the components according to the recipe. The duration of mixing at a temperature of 12...16 °C is 150...250 s, followed by forming the product and placing it in FCE (Fig. 1, item 2) with further frying at a temperature of 150...160 °C for 300 s. A model with functionally closed environments has been experimentally proposed for frying chopped meat semi-finished products (Fig. 1). A feature of the hardware and technological solutions is heat supply under the conditions of convective-infrared heat supply, the formation of excess pressure in FCE during frying intensifies the process and allows partial absorption of the moist and fatty medium after artificial cooling. This is realized by supplying cold water through the liquid injection/flow pipeline (5) connected to the tubular heat exchanger (3) – cooling the FCE (2) and the cylindrical platforms (1) as a whole. Also, the device has a ring of Peltier elements (4), which form –3...–6 °C on its cold surface, autonomously reducing the temperature of the coolant to 10 °C.

A study of mass transfer during frying of chopped meat semi-finished products in functionally closed environments was carried out (Fig. 1, item 2). It was found that during 30 s of frying the test samples in FCE, the pressure is equal to $9 \cdot 10^3$ Pa, during 90 s – $28 \cdot 10^3$ Pa, for 120 s – $35 \cdot 10^3$ Pa, for 210 s – $40 \cdot 10^3$ Pa, and at 300 s – $42 \cdot 10^3$ Pa, respectively. Therefore, the pressure increase in FCE is predictable and depends on the duration of heat treatment, and the pressure is a direct dependence of the obtained temperature in the middle of the sealed environment.

The dynamics of the rate of mass loss of meat products during frying in comparison with traditional frying with a step-by-step reversal in time (180 s and 360 s) are pre-established. And also under the conditions of single-operation frying in FCE with artificial cooling based on a heat exchanger with cold water and Peltier elements and natural cooling of FCE. For control samples in the first period of frying, the maximum heating rate is $3.45 \cdot 10^{-5}$ kg/s for 100 s, in the 2nd period – $2.2 \cdot 10^{-5}$ kg/s for 200 s and in the 3rd period , which is responsible for the formation of the crust of the sample – $1.42 \cdot 10^{-5}$ kg/s for 285 s, respectively (Fig. 3). Frying of experimental samples in FCE with artificial cooling based on a heat exchanger with cold water and Peltier elements has the following characteristics of the dynamics of mass changes. In the first period, $5.7 \cdot 10^{-5}$ kg/s for 98 s with a subsequent decrease in the rate of mass loss to $2.15 \cdot 10^{-5}$ kg/s for 165 s under the conditions of the actual achievement of the 2nd period and the formation of a crust. Frying of experimental samples in FCE under the conditions of their natural cooling is characterized by slower mass growth in the first periods for 165 s. The maximum value was reached in 85 s ($4.42 \cdot 10^{-5}$ kg/s) and the minimum value was $1.65 \cdot 10^{-5}$ kg/s.

During natural cooling of FCE, the rate of change in fat content increases within the range of $(15.2...59.6) \cdot 10^{-3}$ %/s, which is actually 2 % of the total rate, after which the internal layers are heated to the temperature of fat melting and the subsequent formation of intensive fat secretion on levels of 3.1 % at a process speed of $64.3 \cdot 10^{-3}$ %/s (Fig. 4). In the 3rd period, the fat content of the products actually decreases by 4 % with a simultaneous decrease in the speed of the frying process to $13.1 \cdot 10^{-3}$ %/s.

The dynamics of frying chopped meat products in FCE with artificial cooling on the basis of a heat exchanger with cold water and Peltier elements for the 1st periods of loss, the rate is about $52.6 \cdot 10^{-3}$ %/s, for the 2nd it is virtually unchanged. The maximum difference in changes in the fat medium is 120...150 seconds of frying and actually reaches 12.0 % of the total fat content. Frying periods are: 100; 60; and 140 s, respectively. At the end of the frying process, the total content of fatty medium is about 5.3 %, thereby confirming the effectiveness of using artificial cooling.

The difference between the experimentally obtained practical data and the existing technological and equipment analogs when frying meat semi-finished products is the use of high- and metal energy-intensive heating elements. It is observed that there is no possibility of using functionally closed environments, the difficulty of controlling the temperature range, significant mass consumption and a hard shell, in addition, the devices do not have resource-efficient technologies, all this affects the competitiveness of production as a whole [20, 21].

The limitation of the study in improving the method of production of fried chopped meat semi-finished products in functionally closed environments with the addition of blended dried semi-finished products is the need to take into account the FFI properties in order to obtain the predicted nutrient composition. Failure to comply with the established equipment and technological solutions for the implementation of the method of production of fried meat semi-finished products will reduce the competitive properties and quality of finished products.

One of the shortcomings of our research is the lack of a substantiated content of blended dried semi-finished products in the recipes of chopped meat semi-finished products, thereby requiring experimental and practical research into this area. The substantiation of the content of dried natural blends will allow obtaining a rational nutrient composition for daily use of products, minimizing the synthetic component, and obtaining original organoleptic properties under the conditions of innovative engineering solutions.

7. Conclusions

1. A technique for the production of blended dried semi-finished products based on Jerusalem artichoke, pumpkin, and zucchini has been developed. The peculiarity of the technique is the application of the process of pre-concentration of the puree in RPA (55...60 °C) for 0.85...0.9 s to a content of 25...30 % DM and drying in a roller dryer at a temperature of 50...60 °C to a content of 3...6 % DM. It was established that the maximum water absorption capacity of the dried mixture at 23 min. increases by 6.1 % compared to bread. The analysis of the chemical composition confirms a much higher content of FFI in the dried blend: 6 times more potassium, 4 times more calcium, and 31 times more dietary fiber. This confirms the greater effectiveness of using the dried mixture as an absorbing component of the water-fat medium when frying chopped meat semi-finished products.

It is proposed to add blended dried semi-finished product to the recipe of chopped meat products with further frying in an experimental apparatus in functionally closed environments and artificial cooling based on a heat exchanger with cold water and Peltier elements. The process is carried out at a temperature of 150...160 °C for 300 seconds.

2. The dynamics of the rate of mass loss of meat products during frying were established in comparison with traditional frying with a step-by-step overturning over time, as well as under the conditions of single operation frying in FCE with artificial cooling based on a heat exchanger with cold water and Peltier elements and natural cooling of FCE. In control samples during the 1st period of frying, the maximum heating rate is $3.45 \cdot 10^{-5}$ kg/s for 100 s, in the 2nd period – $2.2 \cdot 10^{-5}$ kg/s for 200 s, and for period 3 – $1.42 \cdot 10^{-5}$ kg/s (285 s).

Frying of test samples in FCE with artificial cooling based on a heat exchanger with cold water and Peltier elements is characterized in the 1st period by $5.7 \cdot 10^{-5}$ kg/s for 98 s. After that, there is a further decrease in the rate of mass loss to $2.15 \cdot 10^{-5}$ kg/s for 165 s under the conditions of the actual achievement of the 2nd period and the formation of a crust. Frying the experimental samples in FCE under the conditions of their natural cooling, the maximum value was reached in 85 s ($4.42 \cdot 10^{-5}$ kg/s) and the minimum value was $1.65 \cdot 10^{-5}$ kg/s.

With natural cooling of FCE, the rate of change in fat content increases within the range of $(15.2...59.6) \cdot 10^{-3}$ %/s, with heating of the inner layers to the melting temperature of fat and intensive fat secretion at the level of 3.1 % at a speed of $64.3 \cdot 10^{-3}$ %/s. In the 3rd period, the fat content of the products actually decreases by 4 % with a simultaneous decrease in the speed of the frying process to $13.1 \cdot 10^{-3}$ %/s.

The dynamics of frying chopped meat products in FCE with artificial cooling on the basis of a heat exchanger with cold water and Peltier elements for the 1st periods of loss, the rate is about $52.6 \cdot 10^{-3}$ %/s, for the 2nd it is virtually unchanged. The maximum difference in changes in the fat medium is 120...150 seconds of frying and actually reaches 12.0 % of the total fat content. At the end of the frying process, the total content of fatty medium is about 5.3 %, thereby confirming the effectiveness of using artificial cooling.

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.

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