

The object of the study is the process of smoking a molded meat-vegetable product with the addition of a dried semi-finished product of a high degree of readiness based on Jerusalem artichoke, zucchini, and carrots.

Combined health products will satisfy the demand of end users for functional products of the new generation and will solve the technological problems of manufacturers in accordance with European competitiveness procedures. They will expand the offer of products with rational nutritional, taste, aesthetic characteristics that will meet the modern trends of craft producers, NoReCa business, and consumer expectations.

A universal device for heat treatment of meat and vegetable products under hot and cold smoking conditions has been designed based on a film-like resistive electric heater of the radiating type. The device uses Peltier elements placed on the outer surface of the smoke generator and, at a temperature of 45 °C, they form a low-voltage power supply (~3...4 W) from the conversion of secondary heat. Cold smoking is carried out in the temperature range up to 25 °C, provided that the outer surface of the heater is covered with a coil heat exchanger through which the coolant passes. During hot smoking, the air medium is in the heat exchanger (additional thermal insulation of the chamber).

The uniformity of the temperature field of the meat-vegetable product (meatloaf with a diameter of 0.08±0.01 m) during hot smoking has been confirmed, provided that the center of the loaf reaches 65 °C and the total duration of the process is 5.5 hours. The introduction of dried semi-finished products of a high degree of readiness into the recipe of meat loaves increases the yield of the product by 18 % and the mass fraction of protein by 25 %. The moisture retention capacity of the experimental meat product increases by 11 % with a 33 % decrease in calorie content, which indicates an improvement in its quality indicators compared to the analog.

**Keywords:** meat and vegetable cooked and smoked products, universal smoking device, hot and cold smoking, film electric heater

# DESIGN OF A UNIVERSAL APPARATUS FOR HEAT TREATMENT OF MEAT AND VEGETABLE COOKED AND SMOKED PRODUCTS WITH THE ADDITION OF DRIED SEMI-FINISHED PRODUCTS OF A HIGH DEGREE OF READINESS TO THE RECIPE

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## 1. Introduction

Balanced rational nutrition of European countries is an integral component of the formation of strong immunity to

existing environmental, chronic, and acquired pathogens, taking into account the conditions of life and the type of human activity [1]. It should be noted that most food products, according to the current nomenclature documents, have

synthetic ingredients (dyes, flavorings, etc.) in their recipes, in most cases of foreign production. This increases the cost of the resulting products in the absence of health benefits, causing the demand for products with natural nutrients, and is the basis of European procedures of managing competitive food enterprises. This emphasizes the urgency of finding ways not only to minimize the use of artificial ingredients but also to increase “health” ingredients due to the use of blended semi-finished products of a high degree of readiness with therapeutic and preventive properties [2].

Innovative mechanisms for managing the competitiveness of enterprises include market research on the analysis of the assortment of meat and vegetable cooked and smoked products, in particular smoked products, taking into account the recipes and the daily consumption ratio, for example, raw smoked, cooked and smoked sausages, fish, etc. [3]. The competitiveness of products based on modern resource-efficient technologies aimed at maximally preserving the useful properties of meat raw materials and the possibility of using secondary energy depend on the high-quality implementation of heat treatment. The minimization of artificial ingredients in the recipes of meat-vegetable cooked and smoked products, in particular sausages in casings, is achieved by replacing them with natural blended plant ingredients obtained during gentle heat treatment, ensuring an increase in the nutritional value of products.

Consumers are the final link in the production chain, and meeting their expectations is an important milestone for conducting scientific and technical research and developing hardware solutions at the stage of designing a food product. The results of market research on consumer testing of the concept of a new food product, which is brought to the market, serve as a marker of the feasibility of scientific and technical development [4]. The rationalization of the resource-efficient equipment and technological component of the production of smoked products with the use of natural ingredients in the recipes and innovative management mechanisms, in particular market research, will form the competitiveness of innovative solutions on the European market. Improving the technique of production of smoked products with the addition of dried semi-finished products of a high degree of readiness according to modern technological and engineering solutions is an urgent task of the food industry in European countries.

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## 2. Literature review and problem statement

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The production of culinary products for everyday use under conditions of innovative hardware and technological solutions by adding natural nutrients to the recipe composition, replacing synthetic ingredients will form an assortment of combined and rational food products, including smoked products [5, 6]. As a result of the challenges related to the consequences of Covid 2019, the war in Ukraine, inflation and the cost of living are increasing. For the end consumer and society as a whole, the goals of sustainable development have created a trend towards Fortified/Functional Food with a reduced impact of food products on the environment. The transition to green production and responsible consumption is taking place at a slow pace, especially in regions that traditionally consume meat products. The demand for meat products in the world remains steadily growing, in 2023 the market value of processed meat in the world is esti-

mated at USD 585.5 billion [7]. For the Ukrainian market, smoked meats make up to 25 % of the entire market of meat products and sausages [8]. According to global research by Statista Market Insights, by 2026, the value of the global market for meat snacks will reach USD 11.4 billion [9]. Such a forecast predetermines the prospects for introducing meat snacks with improved properties to the market. Work [10] revealed the effectiveness of using natural plant nutrients for further introduction into the recipes of traditional products of a wide range of use for the formation of functional health-improving and preventive properties. The introduction of blended plant nutrients into the recipes of various products will reduce the composition of synthetic ingredients under the conditions of the formation of original organoleptic and rheological properties and will ensure the support of consumers' immunity to today's environmental challenges. Resource-efficient processing of plant raw materials into semi-finished products of a high degree of readiness (pastes, powders, etc.) is one of the main components of the European management mechanisms of competitive enterprises under the conditions of production of original natural food products [11]. For example, in work [12], the need for a rational selection of plant raw materials, taking into account functional, structure-forming, and organoleptic properties, during the production of culinary products with a rational content of natural nutrients is substantiated. However, the difficulty of obtaining high-quality natural semi-finished products with a high degree of readiness is hardware and technological shortcomings and the lack of ways to increase the resource efficiency of the process as a whole. For example, work [13] revealed the shortcomings of the technological process of plant raw materials processing, taking into account the analysis of the hardware and technological component of the process, in particular metal and energy consumption, emphasizing the need to provide resource-efficient technologies. For example, in work [14], the design of a resource-efficient IR dryer for vegetable raw materials with an optimal geometric shape of the working chamber under the conditions of a uniform thermal field is considered. However, in the production of semi-finished products of a high degree of readiness with a wide range of uses, there is a need to blend raw materials taking into account the natural properties at all stages of production, including meat products. Including the determination of the obtained physicochemical properties and energy value when adding to the recipes of smoked meat products under the conditions of using resource-efficient technologies to obtain functional products [15].

The use of a vegetable blend based on Jerusalem artichoke, zucchini, and carrots will provide original organoleptic, rheological, and immunostimulating properties due to natural nutrients, in particular inulin, while simultaneously minimizing product mass loss during heat treatment [16].

In [13], it is noted that, in addition to inulin, Jerusalem artichoke with the properties of a non-converting carbohydrate makes it possible, due to its moisture-retaining abilities, to minimize sap secretion and even increase the content of fat-containing medium. Carrots and zucchini, in addition to moisture-retaining properties, will make it possible to reduce the recipe content of the meat fraction due to substitution and giving the product original organoleptic properties. In turn, the introduction of dried blend into smoked meat products will make it possible to reduce their calorie content, and therefore to obtain a functional culinary

product for everyday use under conditions of minimization and absence of the need to use synthetic ingredients. This approach emphasizes the need for further detailed research aimed at the rational processing of plant raw materials into semi-finished products of a high degree of readiness and their influence on the obtained properties of ready-made food products.

In [17], an apparatus for low-temperature processing of meat raw materials is considered. It was established that for pork, the processing temperature is 53...80 °C with a duration of 5.0...8.0 hours, 65...80 °C with a duration of 4.5...6.0 hours for poultry. For tender beef – 55...80 °C with a duration of 5.0...8.0 hours and 58...83 °C with a duration of 5.0...10.0 hours for hard beef. But the work does not reveal the effect of plant raw materials on the final properties of culinary products, emphasizing the relevance of research into this area. Thus, work [18] confirms the need for the production of functional food based on resource-efficient technologies based on an automatic quality assessment system. However, this evaluation system for the production of meat culinary smoked products is not a full-fledged quality evaluation matrix, focusing on the feasibility of a comprehensive study from market analysis to recipe and equipment components.

In work [19], the design of hot smoking using smoke-air media is given, but attention is focused on the need to prevent the deposition of synthetic particles, which can cause negative reactions in the consumer's body. One of the solutions is given in [20], where marinated pork breasts were smoked using smoking materials for 40 minutes under the conditions of using a filter based on nanoactivated carbon fiber. However, this complicated the design, maintenance, and cost of finished products. The synthetic component of the smoke-air environment has no benefit for humans in comparison with natural raw materials (wood: alder, cherry, etc.), confirming the need for research into the development of a smokehouse based on natural wood.

Work [10] tested the technology for the production of semi-smoked sausages with the addition of goji berry powder in a concentration of 0.3...0.7 % to the meat. Sausage samples with goji berries showed higher water-holding capacity but lower water activity (1.3-fold at  $p \leq 0.05$ ) compared to control. The histological analysis did not reveal significant structural differences between the experimental and control samples. However, the introduction of individual plant raw materials into the recipe of smoked products does not provide a wide range of possible rheological and organoleptic properties, requiring further research under the conditions of using blends of a high degree of readiness.

Work [5] presents an apparatus for low-temperature processing of meat products with IR radiation based on a film-like resistive electric heater of the radiating type with a uniform distribution of the heat flow. However, the design does not allow smoking under the conditions of the proposed structural solutions, thereby limiting the range of products and requiring the search for solutions to expand the range of smoked meat products. For example, in work [21] the heat and mass exchange during the heat treatment of minced meat products under the conditions of smoking at a temperature of 80 °C for 5 hours with a smoke-air environment was investigated. However, the work did not take into account the method of heat supply, and therefore the provision of a uniform thermal field and heating of the product from the heating surface to the center of the product, which led to

overdrying of the surface layer. Emphasizing the need to ensure uniform heating, taking into account both operating parameters and the uniformity of the temperature field in the working chamber. Work [22] shows the results of cooking meat culinary products by the “sous-vide” method. Physico-chemical characteristics of veal, vegetable, and hybrid cutlets were determined. Test samples with different recipes were processed under variable pressure (350...600 MPa) for 5...15 min with “sous-vide” (55...65 °C for 15 min). It was found that plant-based cutlets were similar to veal cutlets in terms of color and texture parameters, while the physicochemical parameters of plant-based cutlets differed from veal cutlets.

The demand for high-quality food products of the new generation is presented both by end consumers and representatives of the B2B market. Production of cooked and smoked meat and vegetable products (sausages in casings, smoked, and others) with the addition of dried semi-finished products of a high degree of readiness based on a mixture of Jerusalem artichoke, zucchini, and carrots. This will simultaneously cover the demand of end users for functional products and solve the technological problems of manufacturers. It will also allow reducing the specific weight of meat raw materials due to the introduction of plant components, improving the quality of the product (reducing the amount of moisture while preserving the juiciness of the product) and using secondary energy for production. Therefore, the development and introduction of competitive meat and vegetable products, including cooked and smoked products using innovative structural and technological solutions to expand the range of meat products, under the conditions of adding natural ingredients to their recipes, is urgent.

The introduction of blended dried semi-finished products of a high degree of readiness will make it possible to obtain the predicted nutritional and physico-chemical composition of products with original properties, and the combination of hot and cold smoking in one device will expand the structural functionality. Most of the equipment and technological solutions for the production of smoked products do not provide the above-mentioned functional properties, use synthetic smoke-air environments and synthetic recipe ingredients that are not useful for the formation and maintenance of consumer immunity. Conducting experimental and practical research to ensure competitive advantages in obtaining smoked products with the simultaneous addition of natural nutrients to their recipes is an integral component of “health-preventive” food products.

However, most of the equipment for thermal processing of meat and vegetable cooked and smoked products has certain hardware and technological shortcomings related to the complexity of controlling the uniformity of thermal processing and the impossibility of implementing hot and cold smoking in one device. This leads to significant mass loss during heat treatment with possible overheating of certain layers of raw materials, significantly reducing competitive organoleptic and quality properties. Existing traditional equipment has a low level of resource efficiency under conditions of an uneven thermal field with missing structural elements for the use of secondary energy for technical and technological needs (autonomy of certain elements, etc.). An important task during the design of competitive devices is the uniformity of heat flow, preservation of natural properties of raw materials, reduction of weight loss, and use of secondary energy, leading to the need for experimental and

practical research to ensure the above-mentioned advantages. This will also expand the assortment of meat and vegetable cooked and smoked products with the addition of dried semi-finished products of a high degree of readiness to the formation of original taste properties.

### 3. The aim and objectives of the study

The purpose of our research is to design a universal apparatus for thermal processing of meat and vegetable cooked and smoked products with the addition of a dried semi-finished product of a high degree of readiness based on a mixture of Jerusalem artichoke, zucchini, and carrots to the recipe. This will make it possible to expand the range of cooked and smoked meat and vegetable products, including those in cellulose and protein casings, which will increase the content of natural nutrients and minimize mass consumption during heat treatment with original organoleptic properties.

To accomplish the aim, the following tasks have been set:

- to determine the market feasibility of implementing the development of a universal device for the heat treatment of meat and vegetable cooked and smoked products with the addition of dried semi-finished products of a high degree of readiness to the recipe by means of a marketing study of consumer perception of the new product;

- to develop a conceptual solution regarding the design of the apparatus for the heat treatment of meat and vegetable cooked and smoked products under hot and cold smoking conditions;

- to investigate the process of smoking a molded meat-vegetable product with the addition of a dried semi-finished product of a high degree of readiness based on Jerusalem artichoke, zucchini, and carrots with the determination of the physico-chemical properties and energy value of the final product.

### 4. The study materials and methods

The object of this study is the process of smoking a molded meat-vegetable product with the addition of a dried semi-finished product of a high degree of readiness based on Jerusalem artichoke, zucchini, and carrots.

The research hypothesis was as follows. The development of a conceptual solution regarding the design of the apparatus for the heat treatment of meat and vegetable boiled and smoked products under the conditions of hot and cold smoking will allow further development of a competitive apparatus. Addition to the recipe of dried semi-finished meat products of a high degree of readiness based on the proposed mixture of Jerusalem artichoke, zucchini, and carrots will ensure an increase in product yield and moisture retention capacity.

Research was carried out at the State Biotechnology University (Kharkiv, Ukraine). The meat-vegetable product was made by adding to the recipe a dried semi-finished product based on a mixture of Jerusalem artichoke (Interest variety), zucchini (Marcella F1 variety), and carrots (Baltimore F1 variety) with a high content of natural nutrients. The Kharkiv region's natural raw material base with an indication of the chemical composition was used for the production of dried semi-finished product with a high degree of readiness (Table 1 [23–25]).

Table 1

Chemical composition of plant raw materials for the production of dried semi-finished products of a high degree of readiness [23–25]

Physiologically functional ingredients	Raw material (100 gr)		
	Artichoke	Zucchini	Carrot
Vitamin A, µg	2.3	0.1	8.1
Vitamin B <sub>1</sub> , mg	0.73	0.28	0.06
Vitamin B <sub>2</sub> , mg	0.06	0.03	0.07
Vitamin B <sub>9</sub> , µg	18.0	14.4	9.4
Vitamin PP, mg	1.73	0.55	1.1
Vitamin C, mg	6.8	14.2	5.5
Phosphorus, mg	80.3	15.6	56.0
Calcium, mg	16.5	9.3	22.0
Potassium, mg	45.6	27.3	45.8
Mono - and disaccharides, mg	3.3	4.3	6.7
Dietary fibers, g	4.1	1.6	2.5
Organic acids, g	0.1	0.13	0.35
β-carotene	11.4	8.6	12.4
Calorie content, kcal	58.6	23.6	32.0

The dried semi-finished product of a high degree of readiness for the recipes of meat-vegetable semi-finished products with subsequent smoking in a cellulose or protein shell was realized as follows: the plant raw materials were washed, inspected, and cut (8...15 mm). Jerusalem artichoke was pre-blanching with hot steam at a temperature of 100...105 °C for 3...6 minutes. Zucchini was blanched with water at a temperature of 80–90 °C for 2–4 min with preliminary exposure in a 10 % solution of sodium chloride (NaCl) at a temperature of 20 °C for 40 min. Carrots were pre-boiled in water at 80–95 °C for 2–4 minutes. The prepared raw materials were dried in a universal IR dryer placed directly in the production premises at a mild temperature (45...55 °C) to preserve natural nutrients (final content of dry matter (DM) – 6...12 %).

To ensure the production of combined meat-vegetable and dietary sausage products, a meat loaf of the “Rodyna Sausage” trademark was chosen as a control, which, according to the technological process, belongs to the group of cooked and smoked products. According to the technological process of the meatloaf recipe, the output of the control sample and the obtained experimental one was determined, taking into account the introduction of a dried semi-finished product of a high degree of readiness.

The preparation of minced meat for further smoking of the meat-vegetable product was carried out as follows according to the recipe ratio: chicken meat – 37 kg/100 kg of unsalted raw material. Pork meat 14.5 kg/100 kg of unsalted raw material was previously ground; water – 16.5 kg; egg melange and dried semi-finished products of a high degree of readiness – 2.5 kg per 100 kg of unsalted raw materials; salt – 1.25 kg per 100 kg of unsalted raw materials. Homogeneous minced meat was formed in a shell for homogeneity of the structure during heat treatment at a temperature of 65 °C in the center of the loaf with subsequent cooling of the product to 10 °C.

Taking into account the mechanisms of management of the competitiveness of food enterprises, our market research is aimed at determining the relevance of the introduction of innovative technologies for the production of meat-vegetable sausage products with dried natural nutrients and the use

of innovative equipment. Natural raw materials with a high content of nutrients are chosen as the basis of the blend, namely: Jerusalem artichoke, zucchini, and carrots, which were subjected to gentle heat treatment. The step-by-step implementation of the proposed actions will make it possible to expand the range of original smoked sausage products by adding natural ingredients to the recipe (inulin, vitamin C, etc. [26]). A 5-point Likert scale was used to assess consumer perception of the product. The functional parameters of the product were evaluated: "Usefulness of the product"; "Convenience of consumption"; "Aesthetics of the product", as well as emotional characteristics: "Product for communication in the company"; "Product for mood"; "Product for health needs". Physico-chemical properties were determined according to current methods of determining moisture, protein, carbohydrates, and other specified indicators. The studies were repeated in 5-fold repeatability with a relative error of no more than 3 % in accordance with traditional procedures for processing experimental and practical data.

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## 5. Results of investigating the effectiveness of the proposed structural and technological solutions in the production of meat and vegetable sausage products

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### 5.1. Market study of the relevance of the production of meat-vegetable sausage products

Meat and meat products are an important source of protein in the human diet. Their consumption depends on socio-economic factors, religious beliefs, traditions, marketing incentives [27], ethical patterns of consumer behavior related to care for the environment and animal welfare [28]. Awareness of the health problems associated with meat consumption also influences consumer choices. Research shows that personal health is an important factor in consumer choice [29]. Consumers, choosing a food product, take into account its impact on health. During the lockdown, the demand for meat-vegetable sausages increased. Rational factors of consumer demand were replaced by emotional ones, which changed the pattern of consumer behavior [30]. The terminal factors of consumer perception of a new combined meat-vegetable and dietary product brought to the market are taken into account in the process of production of food products with improved properties.

In order to determine the market feasibility of implementing the development of a universal device for thermal processing of meat-vegetable sausage products with the addition of dried semi-finished products of a high degree of readiness to the recipe, a market study of consumer perception of the new product was conducted. Meat and vegetable sausage products belong to the traditional dishes of European countries. The proposed device makes it possible to produce meat and vegetable products by cold and hot smoking under conditions of enrichment with natural nutrients of plant origin (artichoke, zucchini, carrots). The perception of the new concept of a traditional meat-vegetable product was tested using the example of "meatloaf" with an improved nutrient composition of the middle price segment "Smoked meatloaf". The novelty of the combined meat-vegetable/dietary product is:

- 1) in the ingredient composition of the product;
- 2) in the process of processing – smoking in the traditional way;

- 3) employing a universal device for heat treatment using secondary energy.

The research was conducted throughout 2023 via all electronic channels using online questionnaire methods using Google Forms for academic purposes. 423 respondents aged 18 to 65 took part in the study. After sorting out the questionnaires, 420 questionnaires were admitted to the analytical procedure. The results of the survey proved that the majority of respondents are ready to use combined smoked meat-vegetable/dietary products with an improved nutritional composition to pamper themselves (86 % of respondents), on a regular basis to ensure satiety (35 %), for a snack (53 %), for communication and socializing with friends (on holidays) 93 %. To the question of whether consumers perceive the combined smoked meat-vegetable product: "Smoked meat loaf" with an improved nutrient composition as a healthy snack, 34 % answered "yes", 39 % "no", and 27 % could not decide.

Ranked by parametric characteristics of the new combined meat-vegetable product for the respondents are as follows: "Convenience of consumption" (4.9 points), "Usefulness of the product" (4.6 points), "Aesthetics of the product" (4.5 points). The obtained results on psychological factors of product perception, based on emotional characteristics, proved that a new product with the same degree of importance is perceived, first of all, as a product for company communication and a festive atmosphere.

The main requests of consumers for a combined meat-vegetable product for health purposes are related to the naturalness of the product (99 % of respondents); high protein content (96 %); low salt content (95 %); enrichment with inulin (88 %); enrichment with other natural ingredients (56 %). The results confirm the relevance of the production of smoked products with natural ingredients under the conditions of innovative equipment in accordance with European competitiveness mechanisms.

### 5.2. Development of a conceptual solution for the structural design of a universal device for thermal processing of meat and vegetable products

The basis of the universal device for thermal processing of combined meat and vegetable products by smoking is the provision of a uniform temperature field, the use of secondary heat energy for the autonomy of auxiliary equipment, ease of operation, and mobility. To achieve the engineering and technological goal, an apparatus was designed based on a film-like resistive electric heater of the radiating type (FREhRt [31]) and Peltier elements for the conversion of secondary heat energy into a low-voltage supply voltage.

The universal apparatus for heat treatment of combined meat and vegetable products is intended for hot and cold smoking (Fig. 1); it consists of a vertical cylindrical working chamber 1. In the center of the chamber, there is a technical stand 2, the outer part of which is wrapped with FREhRt 3, and in the lower part there are tangentially cut cylindrical ducts with built-in independent fans 4. The tangential placement of cylindrical ducts allows forming a spiral trajectory of the direction of movement of the smoke-air environment under the conditions of the cylindrical surface of the working chamber. The technical rack 2 is connected to the working space of the smoke generator 5, which has an adjustable cylindrical sleeve 6 for smoke-generating substances (sawdust, chips, etc.). The lower part of sleeve 6 is connected to

an adjustable ignition element 7 to control the smoldering speed, as well as a technical valve to control the supply of fresh air to the smoldering chamber 8.

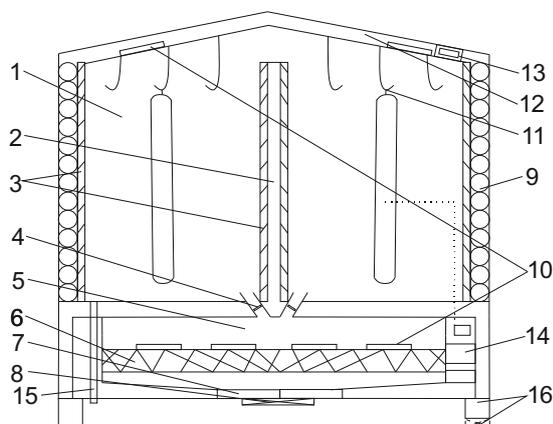


Fig. 1. Scheme of the design of the universal apparatus for heat treatment of combined meat and vegetable products: 1 – cylindrical chamber; 2 – technical rack; 3 – a film-like resistive electric heater of the radiating type (FREhRt); 4 – autonomous fans; 5 – smoke generator; 6 – cylindrical sleeve; 7 – adjustable ignition element; 8 – technical latch; 9 – coil heat exchanger; 10 – Peltier elements; 11 – hooks; 12 – conical cover; 13 – exhaust fan; 14 – thermoregulator “TPM-309” with a needle thermocouple; 15 – technological openings; 16 – legs

The inner surface of the cylindrical chamber 1 is wrapped with FREhRt 3 to implement hot smoking with a temperature range of up to 120 °C. And for the implementation of cold smoking (up to 25 °C), the outer surface of the FREhRt, which forms chamber 1, is covered with a coiled heat exchanger 9, through which the coolant (water) passes as needed to maintain the temperature range. During hot smoking, there is an air medium in the heat exchanger 9, which is an additional thermal insulation of the working chamber 1. The low-voltage supply voltage for the autonomous operation of fans 4 is generated by the Peltier elements 10 located on the outer surface of the smoke generator and at a temperature of 45 °C. Accordingly, providing ~3...4 W for autonomous operation of fans 4 under the conditions of using secondary heat.

Meat products to be smoked are prepared according to the type of product, if necessary, packed in forming casings (cellulose/protein) with placement on hooks 11 connected to a conical cover 12. Hooks 11 allow both hanging smoking and placing mesh elements (trays) for horizontal smoking, increasing the functionality of the working space of the device. The cone of the lid prevents possible condensation from dripping onto the product during heat treatment, directing it to the hydro-lock, thereby not impairing the organoleptic properties. An autonomous exhaust fan 13 is mounted on cover 12, which is powered by a Peltier element 10 located in the cover layer. To control the temperature range, the universal device is equipped with a thermoregulator “TPM-309” (Ukraine) with a needle thermocouple 14, which makes it possible to turn on/off FREhRt 3 during hot smoking. When the finished culinary product is cooled to 10 °C, provided that the appropriate technological

temperature in the center of the loaf is reached and cold smoking is carried out, the coolant supply valve is regulated.

The juice-containing fraction, which can be formed during smoking, is removed through technological holes 15. The device for the convenience of draining the coolant has 4 legs 16, two of which are 1 cm shorter, forming an angle of the device location of 2°.

Cold smoking in the temperature range of up to 25 °C can last 7...72 hours depending on the type of raw material undergoing technological treatment, taking into account technological regulations. The average shelf life is from a month to a year due to blowing with a smoke-air environment while preserving juiciness and original taste. This is different from hot smoking, in which, in addition to being blown with a smoke-air environment, the product undergoes heat treatment under conditions of uniform distribution of the heat flow in the working chamber to minimize juicing during heat treatment.

### 5.3. Studying the effectiveness of the process of smoking a molded meat product with the addition of a dried semi-finished product

In order to determine the effectiveness of the proposed equipment and technological solutions, the process of hot smoking of a trial sample of a molded meat-vegetable product with the addition of a dried semi-finished product based on Jerusalem artichoke, zucchini, and carrots was investigated in the proposed universal apparatus. For hot smoking, the uniformity of the heat supply to the formed “loaf” from the center of the meat-vegetable product over the entire surface at the set smoking temperature of 80 °C using thermocouples connected to the temperature regulator “TPM-309” is important (Fig. 2).

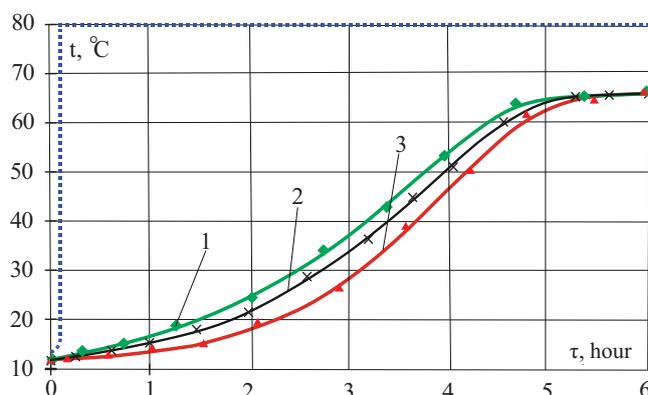


Fig. 2. The process of hot smoking of the molded meat-vegetable product with determination of the temperature on the surface, in the middle, and in the center of the experimental sample: — — duration of FREhRt output to the working temperature (80 °C); 1 – surface temperature; 2 – temperature in the middle layer; 3 – temperature in the center of the experimental product

The predicted uniformity of heat treatment of the molded meat-vegetable product in the designed apparatus was confirmed (Fig. 2). In the first minutes of processing, the surface layer of the sample is heated (curve 1), followed by heating of the middle layer of the molded sample (curve 2) and a gradual transition to the central layer (curve 3). A slight discrepancy is explained by the diameter of the mold-

ed meat product ( $0.08 \pm 0.01$  m), it is not critical and is quite acceptable during the implementation of heat treatment during smoking since the readiness of the culinary smoked product is ensured when the center of the loaf reaches  $65^\circ\text{C}$  in 5.5 hours.

The introduction of a dried semi-finished product of a high degree of readiness based on Jerusalem artichoke, zucchini, and carrots with a significant content of natural nutrients made it possible to obtain the following physico-chemical properties of molded smoked products (example: meat-vegetable meatloaf, Table 2). The dried semi-finished product has high moisture retention properties necessary during heat treatment and competes with traditional phosphates.

Table 2

Physico-chemical properties and energy value of a meat-vegetable product ("Smoked meatloaf")

Indicator	Indicator value (%)	
	control (smoked meat bread of <i>Rodynna Kovbaska</i> retail chain)	experimental meat and vegetable smoked meatloaf with dried semi-finished product of high readiness
Physicochemical properties		
Output	118±0.8	140±0.8
Mass fraction of fats	21±0.6	8.5±0.6
Mass fraction of protein	13±0.7	16±0.7
Mass fraction of moisture	65±0.6	70±0.6
Moisture retention capacity	67±0.8	75±0.8
Mass fraction of carbohydrates	–	5.2±0.7
Energy value		
Proteins	14	17
Carbohydrates	–	5.2
Fats	20.1	7.5
Calorie content, kcal	236.9	156.3

The addition of dried semi-finished products of a high degree of readiness to the recipe of the experimental meat-vegetable bread ensures an increase in the yield of the product by 18 %, and the mass fraction of protein by 25 %. The moisture-retaining capacity of the obtained meat consistency increased by 11 % with the simultaneous minimization of sodium nitrite use and a 33 % decrease in caloric content with an increase in mass moisture in products with reduced caloric content. The introduction of dried semi-finished products preserves the juicy properties of the product during heat treatment, reducing mass loss during traditional heat operations not only on meatloaf, but in general – combined meat and vegetable products enriched with natural nutrients.

## 6. Discussion of the effectiveness of using the designed smokehouse and dried semi-finished products in meat and vegetable products

Perception testing of the concept of a new combined/health food meat-vegetable product "meatloaf" with an improved

nutrient composition of the middle price segment "Smoked meatloaf" was conducted. The novelty of the product is:

- 1) in the ingredient composition of the product;
- 2) in the process of processing – smoking in the traditional way;
- 3) using a universal device for heat treatment using secondary energy.

We conducted research using Google Forms with 420 respondents aged 18 to 65. According to the results of the survey, the majority of respondents are ready to use combined smoked meat-vegetable/dietary products, with an improved nutritional composition, to pamper themselves (86 % of respondents), on a regular basis to ensure satiety (35 %), for a snack (53 %), for communication and socializing with friends (on holidays) 93 %. To the question of whether consumers perceive the combined smoked meat-vegetable product: "Smoked meat loaf" with an improved nutrient composition as a healthy snack, 34 % answered "yes", 39 % "no", and 27 % could not decide. Confirming the market feasibility of implementing the development of a universal device for thermal processing of combined meat and vegetable products with the addition of dried semi-finished products of a high degree of readiness to the recipe.

The basis of the universal apparatus (Fig. 1) for heat treatment under the conditions of hot and cold smoking of meat and vegetable products is the provision of a uniform temperature field, the use of secondary energy for the autonomy of auxiliary equipment, and ease of operation. A film-like resistive radiation-type electric heater is used as a heater, and Peltier elements are used to generate a low-voltage supply voltage. Cold smoking is carried out in a temperature range of up to  $25^\circ\text{C}$ , provided that the outer surface of the heater is covered with a coiled heat exchanger, through which the coolant passes, in case of a need to lower the temperature. To drain the coolant, two of the four legs are 1 cm shorter, forming an angle of the device of  $2^\circ$ . During hot smoking up to  $120^\circ\text{C}$ , there is an air medium in the heat exchanger (additional thermal insulation of the chamber). Peltier elements placed on the outer surface of the smoke generator and at a temperature of  $45^\circ\text{C}$  generate  $\sim 3...4$  W from the conversion of secondary heat, ensuring autonomous operation of fans.

The effectiveness of the proposed equipment and technological solutions in the developed universal smoking apparatus in the process of hot smoking of an experimental sample of a molded meat-vegetable product with the addition of a dried semi-finished product based on Jerusalem artichoke, zucchini, and carrots was investigated. Uniformity of the thermal field is ensured during hot smoking of the molded meat product in the designed apparatus (Fig. 2). At the beginning of processing, the predicted heating of the surface layer of the sample (curve 1) is observed, followed by heating of the middle layer of the molded sample (curve 2), and a gradual transition to the central layer (curve 3). The culinary smoked product is ready at a temperature in the center of the loaf of  $65^\circ\text{C}$  within 5.5 hours.

The growth of physico-chemical indicators and energy value in the experimental sample of meat-vegetable smoked meatloaf with dried semi-finished products of a high degree was confirmed (Table 2). The yield of the product increases by 18 %, the mass fraction of protein by 25 % due to the properties of dried natural nutrients. The moisture retention capacity of the obtained meat consistency increases by 11 %

with a simultaneous decrease in caloric content by 33 % due to the properties of Jerusalem artichoke. The dried semi-finished product preserves the juicy properties of the product during heat treatment, reduces mass loss during traditional heat operations in the production of meat products under the conditions of enriching them with natural nutrients, and eliminates the synthetic component. The difference between traditional equipment and technological analogs for heat treatment of meat and vegetable products is the use of metal-intensive heating elements, synthetic indoor air environments, etc. This makes it difficult to control the temperature regime with the possibility of settling of synthetic particles of the smoke-air mixture on the products, thereby reducing consumer properties [32]. The use of the designed universal apparatus for thermal processing of meat and vegetable products by smoking with the addition of a dried semi-finished product of a high degree of readiness to the recipe will ensure functional competitiveness on the European market. The obtained results confirm the stable demand for combined/healthy meat-vegetable cooked-smoked products with optimistic consumer perception of smoked products with plant ingredients without synthetic additives. Our market research will allow craft producers and NoReCa business to increase competitiveness, expand the offer of combined/healthy meat-vegetable cooked-smoked products that meet nutritional, taste, aesthetic characteristics, modern trends and consumer expectations.

The limitation of the research in the production of meat-vegetable boiled and smoked products with the addition of dried semi-finished products of a high degree of readiness in practice is connected to taking into account the physico-chemical properties of the mixture and the nutrient composition. Failure to comply with the given technological and equipment recommendations, namely deviation from the recipe or readiness of the product at a temperature in the center of the meatloaf at the level of 65 °C, will lead to a decrease in the competitive properties of the obtained products.

Among the shortcomings of practical-experimental research, we can mention the lack of a formed generalized technology of rational smoking regimes, as this requires conducting a wide range of research taking into account raw materials, regimes, recipes, structure formation, mass changes, etc. Further research can be aimed at forming a generalized technological map of the production of rational meat-vegetable cooked and smoked products based on innovative mechanisms for managing the competitiveness of food industry enterprises.

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## 7. Conclusions

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1. Market research was conducted to determine the relevance of the use of combined meat-vegetable cooked and smoked products with natural ingredients; 420 respondents are ready to use them under conditions of improved nutrient composition. To “pamper oneself” (86 % of respondents), on a regular basis to ensure satiety (35 %), for a snack (53 %), for communication and socializing with friends (on holidays) 93 %. It was established that 34 % of consumers of the experimental “Smoked Meat Loaf” with improved nutrient composition consider it a healthy snack. The obtained ranked parametric characteristics of the new product for

the respondents are defined as: “Convenience of consumption” (4.9 points), “Usefulness of the product” (4.6 points), “Aesthetics of the product” (4.5 points). Craft producers and NoReCa business will meet European competitive management mechanisms with an expanded offer of combined meat and vegetable products that meet nutritional, taste, aesthetic characteristics, modern trends and consumer expectations obtained on innovative equipment.

2. A conceptual solution has been developed for the design of the apparatus for thermal processing of meat and vegetable products under hot and cold smoking conditions based on film-like resistive electric heaters of the radiating type and Peltier elements for the generation of low-voltage supply voltage. The implementation of cold smoking is carried out in the temperature range up to 25 °C, provided that the outer surface of the FREhRt, which forms the chamber, is covered with a coiled heat exchanger through which the coolant passes. To drain the coolant, two of the four legs are 1 cm shorter, forming an angle of the device of 2°. During hot smoking, the air medium is in the heat exchanger. The low-voltage supply voltage for autonomous operation of the fans is generated by Peltier elements placed on the outer surface of the smoke generator and at a temperature of 45 °C generates ~3...4 W from the conversion of secondary heat.

3. The uniformity of the temperature field of the meat-vegetable smoked product (meatloaf with a diameter of 0.08±0.01 m) during hot smoking was confirmed, provided that the center of the loaf reaches 65 °C and the total duration of the process is 5.5 hours. The introduction of dried semi-finished products of a high degree of readiness into the recipe of meat loaves increases the yield of the product by 18 % and the mass fraction of protein by 25 %. The moisture-retaining capacity of the experimental meat-vegetable product increases by 11 % with a 33 % reduction in caloric content, which indicates an improvement in its quality indicators compared to analog.

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## Conflicts of interest

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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

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All data are available in the main text of the manuscript.

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## References

1. Galanakis, C. M., Rizou, M., Aldawoud, T. M. S., Ucak, I., Rowan, N. J. (2021). Innovations and technology disruptions in the food sector within the COVID-19 pandemic and post-lockdown era. *Trends in Food Science & Technology*, 110, 193–200. doi: <https://doi.org/10.1016/j.tifs.2021.02.002>
2. Munekata, P. E. S., Pérez-Álvarez, J. Á., Pateiro, M., Viuda-Matos, M., Fernández-López, J., Lorenzo, J. M. (2021). Satiety from healthier and functional foods. *Trends in Food Science & Technology*, 113, 397–410. doi: <https://doi.org/10.1016/j.tifs.2021.05.025>
3. Toldrá, F. (2023). The storage and preservation of meat. III—Meat processing. *Lawrie's Meat Science*, 281–314. doi: <https://doi.org/10.1016/b978-0-323-85408-5.00002-9>
4. Savytska, N. L., Afanasieva, O. P. (2018). Marketynhova polityka pidpriemstv na vitchyznianomu rynku miasa ta miasoproduktiv. Kharkiv: Vydavnytstvo Ivanchenka I. S., 344. Available at: <https://dspace.nuft.edu.ua/jspui/bitstream/123456789/28869/3/meat%20.pdf>
5. Zahorulko, A., Cherevko, O., Zagorulko, A., Yancheva, M., Budnyk, N., Nakonechna, Y. et al. (2021). Design of an apparatus for low-temperature processing of meat delicacies. *Eastern-European Journal of Enterprise Technologies*, 5 (11 (113)), 6–12. doi: <https://doi.org/10.15587/1729-4061.2021.240675>
6. Halagarda, M., Wójciak, K. M. (2022). Health and safety aspects of traditional European meat products. A review. *Meat Science*, 184, 108623. doi: <https://doi.org/10.1016/j.meatsci.2021.108623>
7. Meat Report 2023. Statista. Available at: <https://www.statista.com/study/48827/meat-report/>
8. Tovarna struktura rozdrubnogo tovarooborotu pidpriemstv rozdrubnoi torhivli. Available at: [https://ukrstat.gov.ua/operativ/operativ2018/sr/tsrtp/tsrt\\_u\\_0918.htm](https://ukrstat.gov.ua/operativ/operativ2018/sr/tsrtp/tsrt_u_0918.htm)
9. Value of the global packaged & unpackaged meat snacks market 2019-2026 (2023). Available at: <https://www.statista.com/statistics/1199651/global-packaged-and-unpackaged-meat-snacks-market-size/>
10. Serikkyzy, M., Jumabekova, G., Zheldybayeva, A., Matibayeva, A., Omirbay, R., Balev, D. (2022). Improving the organoleptic and structural-chemical properties of semi-smoked sausages. *Saudi Journal of Biological Sciences*, 29 (3), 1510–1514. doi: <https://doi.org/10.1016/j.sjbs.2021.11.021>
11. McBey, D., Watts, D Johnstone, A. M. (2019). Nudging, formulating new products, and the lifecycle: A qualitative assessment of the viability of three methods for reducing Scottish meat consumption for health, ethical, and environmental reasons. *Appetite*, 142, 104349. doi: <https://doi.org/10.1016/j.appet.2019.104349>
12. BusinesStat, 2020. Market analysis of sausages and meat specialties in Russia in 2014–2018, forecast for 2019–2023.
13. Altenburg, D., Spruyt, A. (2022). Predicting meat consumption from concurrent, automatic appraisals: Introducing nuance to product appraisals. *Appetite*, 170, 105847. doi: <https://doi.org/10.1016/j.appet.2021.105847>
14. Cherevko, O., Mikhaylov, V., Zahorulko, A., Zagorulko, A., Gordienko, I. (2021). Development of a thermal-radiation single-drum roll dryer for concentrated food stuff. *Eastern-European Journal of Enterprise Technologies*, 1 (11 (109)), 25–32. doi: <https://doi.org/10.15587/1729-4061.2021.224990>
15. Sikorski, Z. E. (2016). Smoked Foods: Principles and Production. *Encyclopedia of Food and Health*, 1–5. doi: <https://doi.org/10.1016/b978-0-12-384947-2.00630-9>
16. Illippangama, A. U., Jayasena, D. D., Jo, C., Mudannayake, D. C. (2022). Inulin as a functional ingredient and their applications in meat products. *Carbohydrate Polymers*, 275, 118706. doi: <https://doi.org/10.1016/j.carbpol.2021.118706>
17. Zahorulko, A., Zagorulko, A., Yancheva, M., Serik, M., Sabadash, S., Savchenko-Pererva, M. (2019). Development of the plant for low-temperature treatment of meat products using ir-radiation. *Eastern-European Journal of Enterprise Technologies*, 1 (11 (97)), 17–22. doi: <https://doi.org/10.15587/1729-4061.2019.154950>
18. Sosa-Morales, M. E., Orzuna-Espíritu, R. Vélez-Ruiz, J. F. (2006). Mass, thermal and quality aspects of deep-fat frying of pork meat. *Journal of Food Engineering*, 77 (3), 731–738. doi: <https://doi.org/10.1016/j.jfoodeng.2005.07.033>
19. Sebastian, P., Bruneau, D., Collignan, A., Rivier, M. (2005). Drying and smoking of meat: heat and mass transfer modeling and experimental analysis. *Journal of Food Engineering*, 70 (2), 227–243. doi: <https://doi.org/10.1016/j.jfoodeng.2004.10.002>
20. Wang, S., Guan, R., Huang, H., Yang, K., Cai, M Chen, D. (2021). Effects of Different Smoking Materials and Methods on the Quality of Chinese Traditional Bacon (Larou). *Journal of Food Protection*, 84 (3), 359–367. doi: <https://doi.org/10.4315/jfp-20-223>
21. Ledesma, E., Laca, A., Rendueles, M., Díaz, M. (2016). Texture, colour and optical characteristics of a meat product depending on smoking time and casing type. *LWT - Food Science and Technology*, 65, 164–172. doi: <https://doi.org/10.1016/j.lwt.2015.07.077>
22. Janardhanan, R., Huerta-Leidenz, N., Ibañez, F. C., Beriain, M. J. (2023). High-pressure processing and sous-vide cooking effects on physicochemical properties of meat-based, plant-based and hybrid patties. *LWT*, 173, 114273. doi: <https://doi.org/10.1016/j.lwt.2022.114273>
23. Kasiyanchuk, V. D. (2014). Sukhyi produkt topinambura – efektyvnyi napivfabrykat dlia vyrobnytstva produktsiyi likuvalno-profilaktychnoho pryznachennia. *Halytskyi likarskykh visnyk*, 21 (3), 103–104. Available at: [http://nbuv.gov.ua/UJRN/glv\\_2014\\_21\\_3\\_41](http://nbuv.gov.ua/UJRN/glv_2014_21_3_41)
24. Telezhenko, L. N., Bezusov, A. T. (2004). *Biologicheski aktivnye veschestva fruktov i ovoschey i ikh sokhranenie pri pererabotke*. Odessa: «Optimum», 268.

25. Yudina, T., Nazarenko, I. (2016). Technological parameters and modes of getting mashed zucchini with specified functional and technological properties. *Pratsi TDATU*, 1 (16), 142–149. Available at: [http://elibrary.donnuet.edu.ua/84/1/Yud%D1%96na\\_article\\_23\\_02\\_2016.pdf.pdf](http://elibrary.donnuet.edu.ua/84/1/Yud%D1%96na_article_23_02_2016.pdf.pdf)
26. Afoakwah, N. A., Dong, Y., Zhao, Y., Xiong, Z., Owusu, J., Wang, Y., Zhang, J. (2015). Characterization of Jerusalem artichoke (*Helianthus tuberosus* L.) powder and its application in emulsion-type sausage. *LWT - Food Science and Technology*, 64 (1), 74–81. doi: <https://doi.org/10.1016/j.lwt.2015.05.030>
27. Font-i-Furnols, M., Guerrero, L. (2014). Consumer preference, behavior and perception about meat and meat products: An overview. *Meat Science*, 98 (3), 361–371. doi: <https://doi.org/10.1016/j.meatsci.2014.06.025>
28. Veiga, C. P. da, Moreira, M. N. B., Veiga, C. R. P. da, Souza, A., Su, Z. (2023). Consumer Behavior Concerning Meat Consumption: Evidence from Brazil. *Foods*, 12 (1), 188. doi: <https://doi.org/10.3390/foods12010188>
29. Alarcón-García, M. A., Perez-Alvarez, J. A., López-Vargas, J. H., Pagán-Moreno, M. J. (2020). Meat Snacks Consumption: Aspects That the Consumer Looks for to Consider Them a Healthy Food. *The 1st International Electronic Conference on Food Science and Functional Foods*. doi: [https://doi.org/10.3390/foods\\_2020-07738](https://doi.org/10.3390/foods_2020-07738)
30. Romeo-Arroyo, E., Mora, M., Vázquez-Araújo, L. (2020). Consumer behavior in confinement times: Food choice and cooking attitudes in Spain. *International Journal of Gastronomy and Food Science*, 21, 100226. doi: <https://doi.org/10.1016/j.ijgfs.2020.100226>
31. Zahorulko, A. M., Zahorulko, O. Ye. (2021). Pat. No. 149981 UA. Plivkopodibnyi rezystyvnyi elektronahrivach vprominiuvalnoho typu. No. u202102839; declared: 28.05.2021; published: 23.12.2021, Bul. No. 51. Available at: <https://base.uipv.org/searchINV/search.php?action=viewdetails&IdClaim=279791>
32. Babanov, I., Mikhaylov, V., Shevchenko, A., Mikhaylova, S. (2018). Perspective of roasting method of culinary products with electro-contact heat treatment. *Processes of Food Industries*, 23, 60–66. doi: <https://doi.org/10.24263/2225-2916-2018-23-11>