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SCIENTIFIC ARGUMENTATION AND DEVELOPMENT OF TECHNOLOGIES FOR THE PRODUCTION OF HEALTHY FOOD PRODUCTS BASED ON LOCAL RAW MATERIALS

253.01. Technology of Food Products of Plant Origin

Summary of the doctor habilitat thesis in engineering sciences

CHIȘINAU, 2025

The thesis was developed within the "Food Product Technology and Microbiology" laboratory, PI National Institute of Applied Research in Agriculture and Veterinary Medicine, and within the scientific project: Postdoctoral Project 21.00208.5107.08/PD "Scientific justification and development of manufacturing technologies for healthy food products based on local raw materials"

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CONTENT

CONCEPTUAL GUIDELINES FOR RESEARCH

The relevance and importance of the topic being discussed. The national strategy for healthy eating establishes a series of measures, in which the fortification of foods with macronutrients, including proteins, dietary fiber, and micronutrients (vitamins and minerals), plays an essential role.

In addressing the problem of improving the diet of the socially active population, a significant role is played by the development of a range of food products with increased nutritional value, characterized by a high concentration of functional food ingredients. To supplement the human body's need for vital substances, it is important to consume varied food products, as a homogeneous assortment of products cannot contain the entire spectrum of nutrients.

Scientific and technical achievements in various fields are no longer viewed merely as simple progress, but are increasingly analyzed through the lens of their impact on human health and the environment (Fardet, 2014). The increasing rate of food and raw material production, at the expense of naturalness and safety for human health, has had a significant negative impact. The rapid deterioration of the ecological situation and the increase in the content of synthetic food additives (over 5000 types) in food products have affected their quality and contributed to the appearance of new diseases, called "diseases of civilization". These diseases include: chronic fatigue, hypertension, atherosclerosis, diabetes mellitus, cholecystitis, and others. At the same time, the number of diseases specific to old age, whose causes accumulate throughout life, has increased significantly (Fira-Mlădinescu, 2019).

The consumption level of basic food products in the Republic of Moldova is significantly below the level recommended by rational norms, both in terms of energy value and the structure of the diet (FAO, 2008). Thus, the main objective of the national food sector is the development and production of foods with high biological value, capable of ensuring the optimal intake of vital nutrients, in accordance with the daily requirement recommended for maintaining public health.

A determining factor in maintaining and improving the health of the population is the intensification of natural food product production. In this context, natural foods are frequently associated with those intended for healthy eating. From the perspective of food science, this category includes: products with high nutritional value and increased density of bioactive compounds; foods fortified with vitamins, minerals, polyunsaturated fatty acids, and natural dietary fiber; products intended for specialized nutrition and prophylactic-curative diets; as well as products characterized by a high degree of hygiene and sanitary safety.

In this regard, a distinct sector is emerging within the contemporary food and agri-food industry, that of producing foods for healthy consumption (Pérez-Escamilla, 2017). The main objectives in the field of manufacturing these products consist of: developing new types of products using biologically active preparations and substances; developing innovative technologies for producing superior quality foods with a directionally modified chemical composition, including products intended for mass consumption, for all age categories of the population, considering the specific needs of children and the elderly; and manufacturing differentiated curative-prophylactic products, intended for the prevention of various diseases and the intensification of the body's protective functions (Mincu, 1985; Iușan, 2020).

Based on the completed developments, research has been undertaken aimed at elaborating scientifically grounded recipes and developing innovative food technologies with a significant impact on utilizing local raw materials. The food industry is reacting increasingly actively to public concerns regarding health maintenance, a phenomenon fueled both by the growing consumer awareness of the relationship between diet and health and by the deterioration of statistical indicators regarding the incidence of diet-related diseases (Murray et al., 2006; Iușan et al., 2014).

Current approaches to the prevention and treatment of a wide spectrum of diseases are increasingly based on the use of products with a low content of high-glycemic-index carbohydrates. In this sense, it becomes important not only the quantity and composition of carbohydrates but also the presence of dietary fiber, which significantly influences their absorption rate. The research conducted has paid special attention to the development of advanced manufacturing technologies for fortified extruded products, aiming to improve their nutritional value and functionality. Simultaneously, the composition of functional food products has been detailed, with an emphasis on identifying and integrating bioactive ingredients that can support human health. These research directions aim at optimizing technological processes and formulating innovative food products capable of meeting the current nutritional demands of consumers.

The balanced combination of various plant raw materials in the food manufacturing process allows for their full utilization, increasing the biological and nutritional value of the products while also improving sensory characteristics. It is known that cereals occupy about 73% of the globally cultivated agricultural area and provide about 60% of the total volume of food, being important sources of protein, dietary fiber, vitamins, and minerals. However, the consumption of individual cereals offers inferior nutritional value and sensory properties compared to products obtained by combining them with other plant raw materials. Given that cereal-based foods constitute a fundamental pillar of healthy eating, their integration into the daily diet is necessary (especially when associated with functional ingredients).

The consumption of food products obtained from plant and secondary raw materials, rich in bioactive substances, contributes significantly to strengthening the immune system, preventing chronic diseases, as well as eliminating radionuclides and heavy metals from the body. In this context, the manufacturing of healthy foods, formulated based on plant raw materials containing functional ingredients, represents an important and promising direction in improving public health.

Purpose of the research: The elaboration of scientific and applied principles for the implementation of innovative technologies in the manufacturing of healthy food products, rich in dietary fiber using local raw materials.

Operational objectives:

1. Conducting an in-depth study on the diversification of the healthy food product range, by applying modern and innovative research and development methods, in order to identify effective solutions for improving nutritional value and food safety.
2. Physico-chemical analysis and substantiation of the use of local raw materials with high functional potential, determining the essential technological aspects for obtaining quality food products, in accordance with current healthy eating requirements.
3. Studying the pomace drying process by applying complex technologies (convection and infrared radiation) and optimizing technological parameters (temperature, air speed, load), with the aim of preserving bioactive compounds, increasing energy efficiency, and improving the quality of the final product, based on the mathematical modeling of transfer phenomena.
4. Developing optimal recipes for the manufacturing of functional food products, by utilizing mathematical modeling techniques, based on nutritional principles and dietary requirements, for the formulation of balanced, innovative, and health-beneficial combinations of ingredients.
5. Complex evaluation of the quality of the developed food products, using modern organoleptic, physico-chemical, and microbiological methods, to determine sensory properties, chemical composition, and microbiological profile.
6. Studying the impact of technological factors on the quality of food products intended for a healthy diet, by applying advanced processing technologies, with the aim of optimizing manufacturing processes and increasing product efficiency and safety.
7. Developing modern technological schemes for the production of functional foods, including processing stages, raw material selection, definition of essential technological parameters, and quality control conditions, to ensure an efficient, sustainable process aimed at improving the nutritional and sensory qualities of the products.
8. Determining the nutritional and energy value of the obtained food products, depending on their composition and the technology used, to assess the impact on consumer health and formulate recommendations regarding their integration into a balanced diet.
9. Developing the normative-technical documentation necessary for the industrial implementation of the developed food products, to guarantee compliance with quality and food safety standards under real production conditions.

Research hypothesis: The valorization of local plant raw materials and agro-industrial by-products through the application of modern hybrid technologies, such as convection-infrared radiation drying, can form the basis for the sustainable development of functional foods in the Republic of Moldova. The implementation of a national system oriented towards the rational use of these resources and the advanced modeling of technological processes has the potential to increase the biological value of products, strengthen food security, and promote a balanced and healthy diet at the national level.

Scientific novelty and originality: Innovative technologies were developed for the manufacturing of functional food products intended for healthy nutrition, with a high content of dietary fiber, through the efficient valorization of plant raw materials, cereals, and agro-industrial by-products.For the first time, a differentiated quality assessment method was applied, by comparing with a standard model using the quality unit indicators (Pi), for the complete characterization of these products.

The influence of components from fruits, vegetables, and medicinal plants on the fixation of metallic cations by pectins was established, demonstrating that these components can influence the fixation process.

A mechanism for the binding of metallic cations by pectins in multi-component compositions has been proposed, and a method for estimating the compatibility of pectin with plant ingredients has been developed in order to remove toxic metals from the human body. Based on these results, new principles for the construction of functional food products with predetermined properties were formulated, and biologically active food supplements based on pectin, intended for body detoxification, including from radionuclides, were developed.

Considerable results that contribute to the solution of the scientific problem: Innovative research methods were applied, which allowed for obtaining extruded products with high nutritional value, rich in fiber, protein, and bioactive compounds. Local raw materials were analyzed, highlighting their major functional potential, and plant additives improved the technological properties of the extrudates. The pomace drying processes were optimized through complex technologies, which reduced the processing time by up to 45% and ensured the preservation of bioactive compounds. Optimal recipes were developed, based on mathematical modeling, ensuring balanced combinations of ingredients and high technological stability. Completely safe products were obtained from a microbiological perspective. They have high technological quality, and an economic profitability of 19%. The distinct stages of the drying process and the determinant influence of temperature and infrared radiation on dehydration kinetics were highlighted. Sustainable technological schemes were developed for obtaining functional foods with enhanced nutritional and sensory value. Beneficial biological effects of the products were confirmed, including the reduction of internal radioactivity and the acceleration of the elimination of toxic metals.The industrial feasibility and applicability of the technologies were validated through their implementation in specialized enterprises and the development of technical-normative documentation conforming to standards.

Theoretical significance: The research scientifically substantiates the optimal parameters of the extrusion process for fiber-rich plant raw materials, correlating their composition and structure with the processing conditions. The research led to the formulation of principles regarding the substantiation of raw materials and the adjustment of technological variables (temperature, humidity, time, speed), in order to increase the functional and nutritional value of the products. The results contribute to the expansion of knowledge in food process engineering and provide a theoretical framework for the development of healthy products with an optimized nutritional profile.

Applicative value of the research: The technology for manufacturing extruded products based on cereal raw materials and agro-industrial by-products was successfully tested and validated at the enterprises "Policom-Prim" SRL and "BIOCOM" SRL in Chișinău.

Following the research, draft technical normative acts were developed for the production of biologically active food supplements (BAFS), detoxifying agents, as well as for the development of related functional products. The innovative processes and recipes were confirmed through experimental and industrial testing at "CONSULT LC" SRL.

The implementation of these results will contribute to the expansion of safe and functional food production, the promotion of public health, and the strengthening of the economic competitiveness and export potential of the Republic of Moldova.

Approval of scientific results: The results were presented at 26 national and international scientific conferences, round tables, and specialized exhibitions, including: International Conference *Modern Technologies in the Food Industry*, Technical University of Moldova, Chișinău (2018, 2024); International Exhibition *Food&Drinks*, Chișinău, Republic of Moldova (2015, 2016); INTERNATIONAL BROKERAGE EVENT within the Enterprise Europe Network (EEN), Chișinău, Republic of Moldova (2016); International Exhibition of Inventics “INVENTICA”, Iași, Romania (2018, 2025); European Exhibition of Creativity and Innovation “EUROINVENT”, Iași, Romania (2016, 2017, 2018, 2024, 2025); International Salon of Inventions and Innovations “TRAIAN VUIA”, Timișoara, Romania (2025); Research and Innovation Exhibition “UGALINVENT”, Galați, Romania (2021, 2022); International Specialized Exhibition “InfoInvent”, Chișinău, Republic of Moldova (2017, 2019, 2023); International Scientific and Practical Forum *“Promising Technologies in the Agro-Industrial Complex”*, Krasnodar, Russian Federation (2018); *The 9th International Scientific and Practical Conference “Scientific Horizon in the Context of Social Crises”*, Tokyo, Japan (2021); *III Congress “Science, Nutrition, and Health”*, National Academy of Sciences of Belarus, Minsk, Republic of Belarus (2021); International Scientific Conference *“Biologization of the*

Intensification Processes in Horticulture and Viticulture", Krasnodar, Russian Federation (2021); National Conference with International Participation *"Science in Northern Moldova: Problems, Achievements, Perspectives"*, Bălți, Republic of Moldova (2021); *The 5th International Scientific and Practical Conference: Current Issues and Prospects for the Development of Scientific Research*, Orléans, France (2022); *The 12th International Scientific and Practical Conference: Scientific Research in XXI Century*, Ottawa, Canada (2022); *The 1st International Exhibition of Creativity and Innovation "Excellent IDEA"*, Chișinău, Republic of Moldova (2022); International Salon of Invention and Innovative Entrepreneurship, "Ion Creangă" State Pedagogical University, Chișinău, Republic of Moldova (2024, 2025).

Publications on the thesis topic. The research results and topics addressed in the thesis were published in 41 scientific works, including one monograph, 21 scientific articles, 3 invention patents, and 1 patent application, as well as in 19 articles in abstracts of national and international scientific conferences.

Summary of the thesis chapters. The thesis is structured on 220 typed pages and includes the following chapters: annotation in Romanian and English, introduction, 6 chapters, conclusions and recommendations, proposals for the use of the results obtained in economic fields, a bibliography with 285 sources, and 19 appendices. The work is illustrated with 64 tables and 77 figures.

1. SCIENTIFIC JUSTIFICATION FOR THE DEVELOPMENT OF HEALTHY FOOD PRODUCTS

In recent decades, nutrition and food security have become important topics of national and international research, in the context of the increasing incidence of degenerative diseases, population aging, and environmental changes affecting food quality. Global organizations, including *FAO* and *WHO*, emphasize the need to reform food systems by promoting a sustainable, balanced, and functional diet (FAO, 2008). According to these reports, a healthy diet must ensure a balanced intake: 45–65% carbohydrates, 20–35% lipids, and 10–35% proteins, as well as a significant content of fiber, vitamins, minerals, and bioactive compounds.

More and more studies (Aryal, 2023; Ackman, 2008) emphasize that modern nutrition, dominated by ultra-processed products poor in micronutrients, contributes to metabolic imbalances, obesity, and cardiovascular diseases. In this context, the concept of functional food emerged, first introduced in Japan in the 1980s under the name *FOSHU (Foods for Specified Health Use).* Subsequently, the term was extended at European and global levels, defining food products that, in addition to the basic nutritional function, exert beneficial physiological effects on health, through their content of biologically active substances (BAS): antioxidants, vitamins, polyphenols, unsaturated fatty acids, and dietary fiber (Dahl et al., 2015; Fira-Mlădinescu, 2019).

The specialized literature distinguishes several directions in the development of functional foods: fortification of products with essential micronutrients (vitamins, iron, calcium, iodine); partial substitution of ingredients with alternatives rich in fiber and bioactive compounds; modification of technological processes to preserve beneficial compounds and reduce contaminants (Fardet et al., 2014; Otles et al., 2014). Recent studies demonstrate that the food matrix directly influences the bioavailability of bioactive substances. According to Fardet (2014), the physical structure and composition of the food determine the mode of release and absorption of nutrients, and technological processing can amplify or diminish the functional effect. Therefore, the application of gentle, controlled technologies adapted to the nature of the ingredients becomes an essential condition for obtaining products with high biological value.

One of the most studied modern methods is extrusion technology, analyzed by Alam et al. (2016) and Abramov (2007). This technique allows for the combination of mixing, heat transfer, and denaturation processes, leading to the production of products with a uniform texture, increased microbiological stability, and high digestibility. Extrusion is considered a sustainable and energy-efficient method, recommendable for the valorization of cereals, legumes, and secondary products of the agri-food industry, such as bran or pomace.

Concurrently, the specialized literature pays increasing attention to dietary fiber and its role in maintaining metabolic health. Evert et al. (2006) and Iușan et al. (2014) highlight the beneficial effects of fiber in regulating glycemia, reducing plasma cholesterol, and normalizing intestinal transit. Otles and Ozgoz (2014) supplement this perspective, demonstrating that fiber not only improves health but also contributes to the technological properties of food products, texture, water retention, and emulsion stability.

An emergent direction in recent literature constitutes the integration of sustainable nutrition principles into the development of functional foods. Scientists argue that the use of local plant raw materials, agricultural by-products, and low-environmental-impact processing technologies can lead to obtaining healthy, competitive, and ecological products (Fira-Mlădinescu, 2019; Aryal, 2023). This orientation aligns with global objectives regarding the circular economy and the reduction of food waste through the secondary valorization of plant resources. At the same time, international studies emphasize the interaction between nutrition science and technological innovation. According to Dahl et al. (2015), the efficiency of functional foods depends on the balance between the biochemical composition of the ingredients and the control of transformation processes, which requires interdisciplinary collaborations between nutritionists, food technologists, and biochemists.

In conclusion, the bibliographic analysis demonstrates that the development of functional food products represents a connected domain of modern research, with a major impact on public health, economy, and environmental sustainability.

Contemporary directions aim at the integration of innovative technologies, especially extrusion, combined drying, and natural fortification, with the principles of a balanced diet based on local resources. This approach, theoretically substantiated and consolidated by numerous international studies, outlines the premises for preventive and personalized nutrition, adapted to the requirements of society and the current global context.

2. MATERIALS AND METHODS

The research conducted within the thesis aimed at elaborating the scientific and technological principles for obtaining healthy food products, based on the rational valorization of local plant raw materials and secondary raw materials originating from the food industry. The experimental activities took place in the research laboratory "Food Production Technology and Microbiology" of the National Institute of Applied Research in Agriculture and Veterinary Medicine and focused on identifying the optimal composition of raw materials, evaluating technological parameters, and establishing correlations between the structure of the materials, functional properties, and the biological value of the products obtained.

The cereal raw material was represented by wheat, corn, buckwheat, and soriz—crops with increased nutritional value and distinct technological properties. Wheat and corn were chosen for their balanced content of proteins and carbohydrates, for their capacity to generate extruded products with high digestibility, while buckwheat and soriz, due to their rich content of essential amino acids, vitamins, and minerals, were valorized for the purpose of obtaining gluten-free products, recommended for people with gluten intolerance.

The plant raw material included local fruits and vegetables, plums, apricots, peaches, sour cherries, peppers, zucchini, carrots, pumpkin, tomatoes, as well as berries and medicinal plants, such as black currant, raspberry, aronia, marigold, and St. John's wort flowers. These were selected for their increased content of phenolic substances, carotenoids, organic acids, and antioxidant vitamins, thus contributing to the increase in the functional value of the obtained products.

Special attention was given to the valorization of secondary raw materials originating from the milling, canning, and fruit processing industries, considered until recently as waste with low economic value. This category includes bran, grape and apple pomace, as well as tomato waste—natural sources of dietary fiber, polyphenols, organic acids, vitamins, and microelements. These materials were reintroduced into the technological cycle in the form of plant powders or functional additives, with the aim of increasing nutritional density and reducing the ecological impact of production processes.

Apple pectin, with a varying degree of esterification, was used as a natural texturizing agent and stabilizer. By adjusting the degree of methylation, the objective was to obtain polymer variants with differentiated rheological properties, offering the possibility of functional adaptation to various categories of food products—from gelled systems, characterized by a stable three-dimensional network, to extruded products with a crispy texture, specific to the expanded solid matrix.

The research included a complex of physico-chemical, microbiological, and organoleptic analyses aimed at the complete characterization of raw materials, semi-finished products, and finished products. Physico-chemical analyses covered the determination of the content of proteins, lipids, carbohydrates, dietary fiber, moisture, and acidity, using classical laboratory methods. Water and oil holding capacity, porosity, swelling index, and total polyphenol content were evaluated to assess the functional behavior of the plant components during processing. In parallel, macro- and microelements (Ca, Mg, K, Fe, Zn, Mn, P) were determined by atomic absorption spectrophotometry, as well as B-complex vitamins and vitamin K. The microbiological evaluation aimed at establishing the degree of product safety, by determining the number of mesophilic microorganisms, yeasts, and molds, as well as by verifying the absence of *Salmonella* bacteria. Organoleptic analyses were performed by an expert panel, which assessed the appearance, color, smell, taste, and consistency of the products, using a five-step evaluation system.

Modern experimental methods were used for the determination of technological parameters, with the exact monitoring of process factors (temperature, humidity, air flow, exposure time), in order to establish the kinetics of transformation processes. An element of novelty in the research is the integrated approach to the drying process of secondary raw materials. Experiments were conducted using the laboratory installation "CIMU-UC07", designed for the comparative study of drying processes by convection, infrared radiation, and combined methods. The installation allows for the adjustment of air flow, temperature, and rotation speed, as well as the continuous monitoring of sample weight loss, thus ensuring the precise determination of the process kinetics. By using this equipment, the optimal drying regimes for grape, apple, and tomato pomace were established, with the aim of preserving bioactive compounds and improving functional properties. The controlled drying procedure allowed for obtaining powders with a stable structure, reduced moisture content, and maintained antioxidant properties, demonstrating the high potential of secondary raw materials in the formulation of functional food products.

Through the use of this equipment, the optimal drying regimes for grape, apple, and tomato pomace were established, with the aim of preserving bioactive compounds and improving functional properties. The controlled drying procedure allowed for obtaining powders with a stable structure, reduced moisture content, and maintained antioxidant properties, demonstrating the high potential of secondary raw materials in the formulation of functional food products.

The research also aimed at determining the optimal parameters for extrusion and product formation, developing corresponding mathematical models for thermal processes, and analyzing the synergistic effects of temperature and moisture on the stability of bioactive compounds.

The selection of raw materials and the methods applied were guided by the principles of sustainability, valorization of local resources, and the protection of bioactive substances during processing. By combining conventional raw materials with non-traditional and secondary sources, the research demonstrated the possibility of obtaining products with high biological and functional value, intended for the prevention of non-communicable diseases.

The complex methodology adopted, which combines modern physico-chemical analyses, sensory evaluations, and technological modeling, allowed not only for the complete characterization of the studied materials but also for the scientific substantiation of the transformation processes, offering solid premises for the transfer of results into industrial practice. Overall, the research methodology reflects an integrated approach focused on technological innovation and a reasonable evaluation of natural and secondary resources, contributing to the development of a modern concept of healthy nutrition based on science, sustainability, and agri-food efficiency.

3. STUDY ON THE IMPROVING THE DRYING PROCESS OF SECONDARY RAW MATERIAL

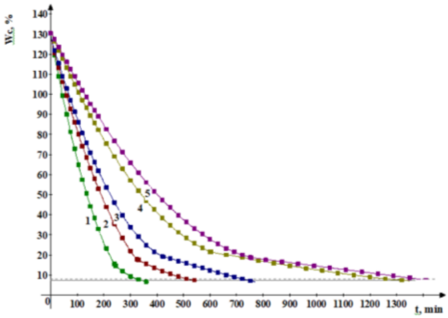
The vegetable pomace drying process is of particular interest due to its potential for valorizing biological waste resulting from fruit processing, offering important applications in the food industry. Pomace, consisting of pulp, seeds, and peels, represents an important source of nutrients and bioactive compounds, especially polyphenols, with valorization potential for obtaining value-added products. The drying process contributes to reducing waste volume, improving the stability and durability of the final product, thus facilitating storage conditions and possibilities for later use. (Li et al., 2017).

Among the methods applied, the most used are hot air drying, infrared drying, and hybrid technologies. Hot air drying is the most economically accessible, but it may require a longer time and can reduce the content of bioactive compounds. Infrared drying offers superior energy efficiency and better retention of active substances, and hybrid methods—combining hot air with infrared radiation—allow for reduced processing time and obtaining a more uniform product with improved nutritional properties (Iușan et al., 2020).

The optimization of these techniques is achieved through mathematical modeling of the drying process kinetics, using empirical or semi-theoretical models (Page, Logarithmic), which allow for the estimation of optimal technological parameters. The research aims to select appropriate models and conditions that ensure the production of high-quality dried products with valuable nutritional and organoleptic properties. (Șleagun, 2024).

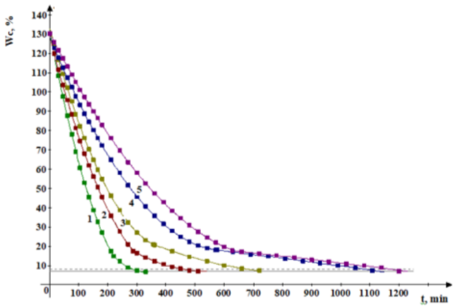
3.1 The kinetics of the drying process for apple, grape, and tomato pomace using convection and convection in combination with infrared radiation, depending on various parameters

The research focused on analyzing the drying process of apple, grape, and tomato pomace, using convective methods and combined techniques based on infrared radiation. The study established the influence of air temperature and radiation on the drying kinetics, energy efficiency, and quality of the final product. The results obtained highlight the relationship between thermal parameters and the characteristics of the dried product, providing directions for optimizing the process in the food industry.



1 – 85 ºC, 2 – 75 ºC, 3 – 65 ºC,4 – 55 ºC, 5 – 45 ºC

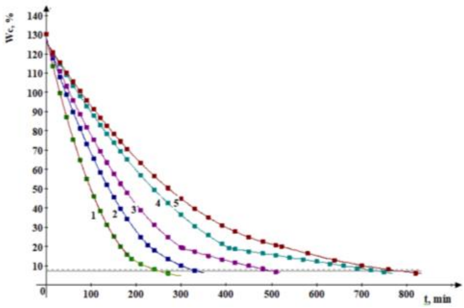
Fig. 3.1 Drying curves of grape using convection with parallel air flow at different temperatures



1 – 85 ºC, 2 – 75 ºC, 3 – 65 ºC,4 – 55 ºC, 5 – 45 ºC

Fig. 3.2 Drying curves of grape pomace using parallel air flow convection and convection combined with 1.33 kW/m^2 IR at different temperatures

Fig. 3.1–3.3 present the drying curves of grape pomace obtained by convection and by convection combined with infrared radiation (1.33 and 2.0 kW/m²) at temperatures between 45 and 85 °C. Increasing the drying air temperature from 45 °C to 85 °C reduced the total process duration by 76% (convection), 75% (IR 1.33 kW/m²), and 68% (IR 2.0 kW/m²). The analysis of the curves indicates that the drying of grape pomace occurs entirely in the falling rate period, characterized by two zones (II-1 and II-2).



1 – 85 ºC, 2 – 75 ºC, 3 – 65 ºC,4 – 55 ºC, 5 – 45 ºC

Fig. 3.3 Drying curves of grape pomace using parallel air convection and convection combined with 2.0 kW/m^2 IR at different temperatures

The critical point W_{cr} II, corresponding to the transition between these stages, was determined in the range of 15.0–21.0% dry matter, representing about 11.5–16.0% of the initial moisture content. Zone II-2, associated with supplementary drying up to 7.0% DM, holds a greater share at low temperatures (44.0–55.0%) and is significantly reduced at 85 °C (25.0–29.0%). Applying infrared radiation of 2.0 kW/m² diminished the total drying duration by up to 45.0% at low temperatures and by 27.0% at 85 °C, demonstrating superior thermal transfer efficiency. The effect is attributed to the selective absorption of radiation by the water in the product and improved thermal penetration. The results confirm the efficiency of the combined IR–convection technology for drying grape pomace, allowing for the reduction of energy consumption and the maintenance of final product quality.

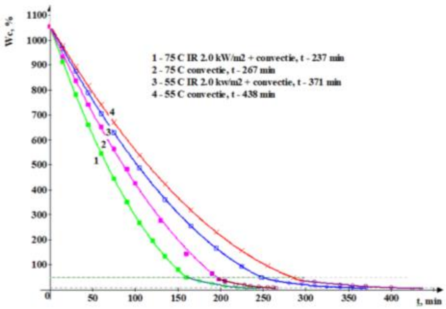
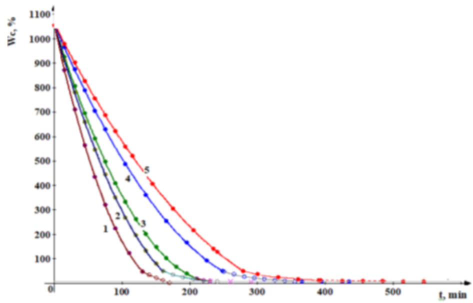


Fig. 3.4 Drying curves of tomato pomace using convection with parallel air flow at temperatures between 55…75°C



1 – 85 ºC, 2 – 75 ºC, 3 – 65 ºC,4 – 55 ºC, 5 – 45 ºC

Fig. 3.5 Drying curves of tomato pomace using parallel flow convection at different temperatures

Fig. 3.4 presents the drying curves under convective regime (55 and 75 °C). Fig.3.5 presents the variation in the moisture content of tomato pomace during dehydration under the action of infrared radiation (2 kW/m²) in a hot air flow (3 m/s), at temperatures between 45...85 °C (combined regime). The drying duration, from 1055 min to 7% moisture (in DM), varied between 546...165 min for the combined regime (45–85 °C) and between 284...196 min for the convective regime (55–75 °C). Increasing the air temperature significantly reduced the drying time in both regimes. At equal temperatures, combined drying was faster than convective drying by 11.2% at 75 °C and by 15.3% at 55 °C, confirming the efficiency of infrared radiation at moderate temperatures. The drying curves show only the falling rate period and an inflection point (the second critical point), located at 51.35±1.17% DM for the combined regime and at 38–44% DM for the convective regime. Zone I (≈95% of the water removed) and Zone II (≈5%) are distinguished by different contributions, the duration of the latter decreasing with increasing temperature, a fact that indicates the need to adjust the drying finishing conditions. These observations are consistent with the results obtained by Bhatkar et al. (2021) and Conte et al. (2024), who confirmed the relevance of two-stage kinetic models for describing the drying process. Similar conclusions regarding the positive effect of infrared radiation on drying kinetics were also obtained by Huang et al. (2021) .

For the analysis of the apple pomace drying process, the W–τ curves (Fig. 3.6–3.8), the drying rate curves dW/dτ–W (Fig. 3.9–3.11), and the variation of the weighted temperature θ–W (Fig. 3.12–3.14) were graphically obtained, highlighting the dynamics of moisture loss and the thermal evolution of the product.

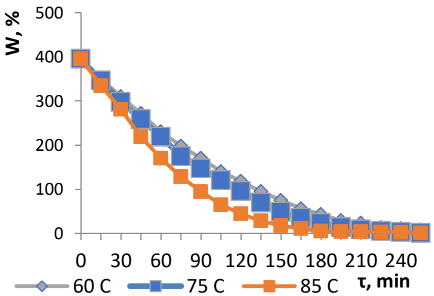


Fig. 3.6 Curves of the drying of apple pomace at a constant speed (v=2m/s) and various air temperatures, ^{0}C: 60, 75, 85.

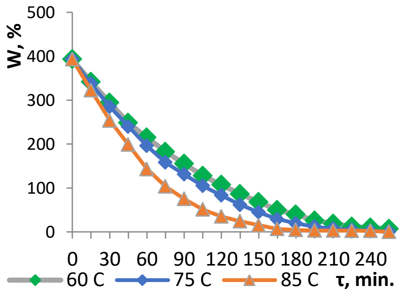


Fig. 3.7 Curves of the drying of apple pomace at a constant speed (v=3m/s) and various air temperatures, ^{0}C: 60, 75, 85.

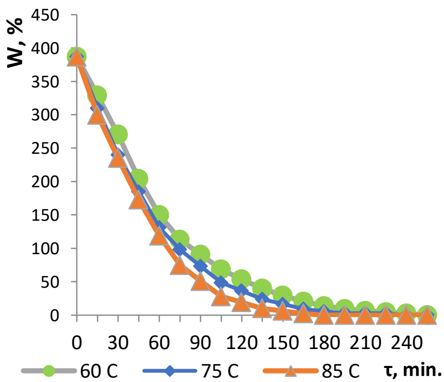


Fig. 3.8 Curves of the drying of apple pomace at a constant speed (v=4m/s) and various air temperatures, ^{0}C: 60, 75, 85

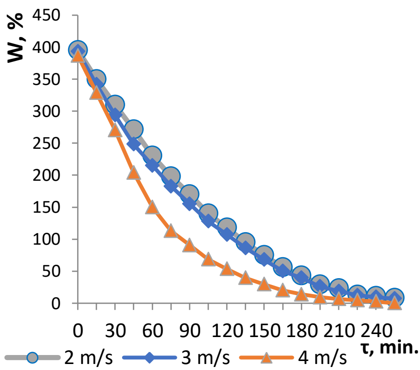


Fig. 3.9 Drying curves for apple pomace at a temperature of 60°C

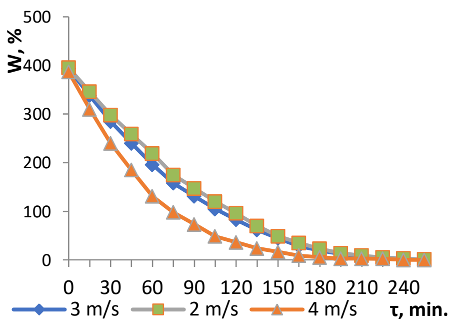


Fig. 3.10 Drying curves for apple pomace at a temperature of 75°C

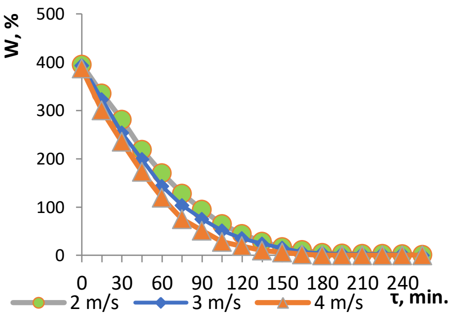


Fig. 3.11 Drying curves for apple pomace at a temperature of 85°C

Analysis of the drying curves (Fig. 3.6–3.11) obtained for dehydrated apple pomace at air speeds of 2–4 m/s and temperatures of 60–85°C highlights the significant influence of technological parameters on the kinetics of the process. Increasing the temperature and air velocity accelerates drying, with the effect being more pronounced between temperatures of 75–85°C, where heat transfer and water evaporation are more intense. Increasing the air velocity from 2 to 4 m/s reduced the process time by 20 minutes per stage, but at 85 °C the additional impact was limited (≈15 minutes), indicating a restriction of the process by internal moisture diffusion. The influence of these parameters is more evident in the initial phase, when humidity is high, and subsequently diminishes as the degree of water binding increases. The results obtained indicate that the optimal regime is at a temperature of 75 °C and an air velocity of 3 m/s, which offers a favorable compromise between energy efficiency and process duration, avoiding overloading the system under extreme conditions.

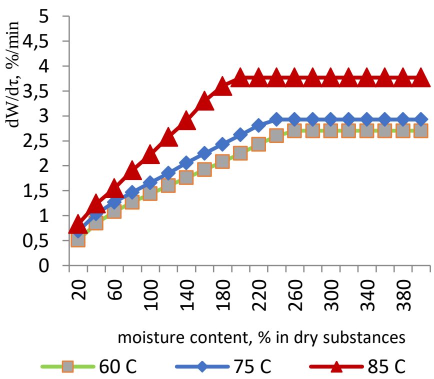


Fig. 3.12 Drying dynamics of apple pomace at constant air speed (v=2m/s) and different temperatures, ^{0}C: 60, 75, 85

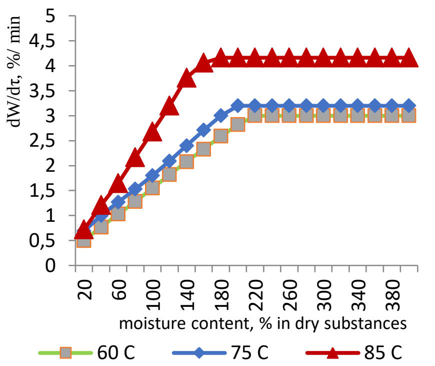


Fig. 3.13 Drying dynamics of apple pomace at constant air speed (v=3m/s) and different temperatures, ^{0}C: 60, 75, 85

Analysis of the apple pomace drying process (Fig. 3.12–3.14) highlights the combined influence of temperature and air velocity on dehydration kinetics. Increasing the temperature from 60 °C to 85 °C significantly intensifies the process, with the maximum drying rate being reached at 85 °C. At the same time, at higher air speeds (3–4 m/s), the differences between the 75°C and 85°C temperature regimes become minor, indicating a reduction in the efficiency of the temperature increase.

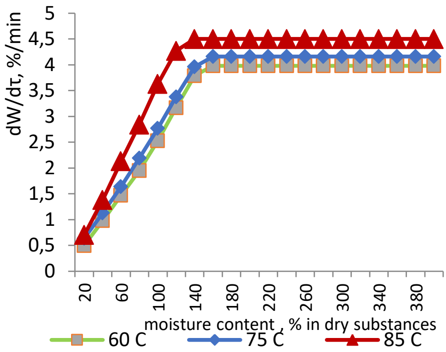


Fig. 3.14 Drying dynamics of apple pomace at constant air speed (v=4m/s) and different temperatures, ^{0}C: 60, 75, 85

At an air speed of 4 m/s, the drying curves are converging lines, and at 85°C there is no noticeable acceleration of the process, which signals that a critical threshold of intensification has been reached. Under these conditions, increasing the air speed above 3 m/s does not bring significant benefits, leading only to additional energy consumption. The results confirm that the optimal conditions for drying apple pomace are a temperature of 75 °C and an air speed of 3 m/s, parameters that ensure a balance between process duration and energy efficiency. The effect of temperature and air speed is predominant in the initial stages of drying, when free water evaporates rapidly, decreasing in the final stages, when water is bound capillarily or molecularly.

Therefore, it is recommended to apply a dynamic, phased regime with high temperature and speed in the initial phase, followed by a finishing phase with moderate parameters, in order to optimize energy consumption and preserve the valuable compounds of the product.

3.2 The dependence of the drying time on the load and temperature during the apple pomace drying process

Numerous studies describe the convective drying process of apples and evaluate the quality of the dehydrated product; only a small number of studies address the drying of apple pomace. Modeling this process is complex due to the heterogeneous composition of pomace, which contains pulp, seeds, skins, and stems in varying proportions (Aidigié et al., 2007). Fig. 3.6–3.11 show the drying curves $W^u=f(\tau)$, and Fig. 3.12–3.14 show the drying rate curves $\frac{dW^u}{d\tau} = f(W^U)$ for air speeds of 2, 3, and 4 m/s and temperatures of 60, 75, and 85 °C.

Data analysis highlights the existence of two distinct periods: the period with constant drying speed and the period with decreasing speed, confirming the observations made by Ceșko et al. (2022). The boundary between them is defined by the critical moisture content W_{cr}^u..

The increase in air temperature from 60 to 85 °C caused the W_{cr}^{u}.values to decrease from 230 to 170 % s.u. (2 m/s), from 215 to 143 % s.u. (3 m/s) and from 150 to 119 % s.u. (4 m/s), simultaneously with an increase in the maximum drying speed (N) in the first period by up to 1.4 times (2–3 m/s) and 1.1 times (4 m/s). The intensification of the temperature effect is more pronounced in the range of 75–85°C.

Also, increasing the air speed from 2 to 4 m/s reduced W_{cr}^{u}.from 230 to 150% s.u. up to 60 °C, from 219 to 131% d.s. up to 75 °C, and from 170 to 119 % d.s. at 85 °C. The maximum drying speed increased 1.5 times between 60–75 °C and 1.2 times at 85 °C. At a temperature of 85 °C, an almost linear dependence between the drying rate (N) and the air speed (V) was observed in the range of 2–4 m/s, indicating a constant intensification of the process at high temperatures.

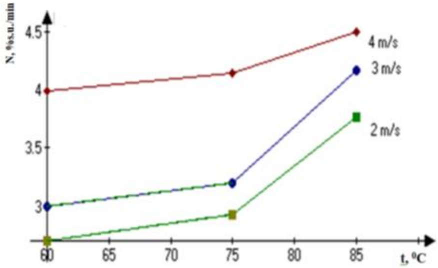


Fig. 3.15 Dependence of the maximum drying speed on the air temperature for different air speeds: 2, 3, and 4 m/s

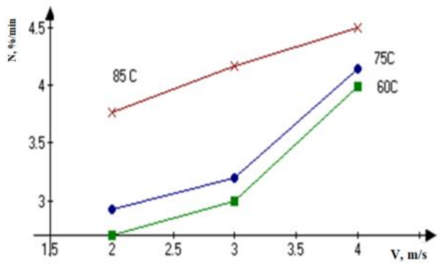


Fig. 3.16 Dependence of the maximum drying speed on air speed for different air temperatures: 60, 75, and 85 °C

Graphical analysis showed that both temperature and air velocity have a significant influence on the speed and duration of the drying process, with the magnitude of the effect varying depending on the technological conditions.

Increasing the air temperature from 60°C to 75 and 85°C resulted in a progressive reduction in the total drying time (from $W_0^u = 393 \pm 3$ % până la W_f^u=8%) with ratios of 1:1.2:1.4 at 2 m/s; 1:1.3:1.5 at 3 m/s and 1:1.2:1.45 at 4 m/s.

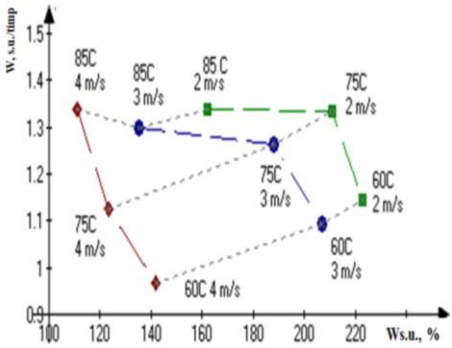


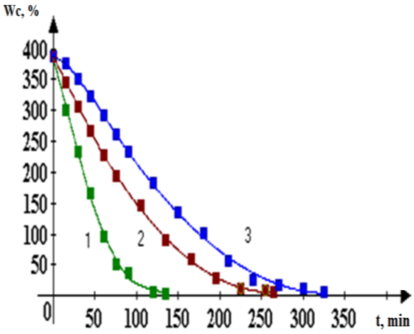
Fig. 3.17 Average drying rate of apple pomace during the decreasing drying rate period depending on the amount of moisture to be removed during this period, W, % d.s.

The duration of the first period represented 24–37% of the total time at speeds of 2–3 m/s and 29–42% at 4 m/s, with 42–58%, 46–65%, and 63–71% of the total moisture evaporating at this stage, respectively. Increasing the air speed from 2 to 4 m/s reduced the total drying time by ratios of 1:1.02:1.23 at 60°C; 1:1.04:1.29 at 75°C and 1:1.10:1.27 at 85°C. The most pronounced reduction was achieved at 75–85 °C and speeds of 2–4 m/s. The ratio of the duration of the first period to the total drying time varied between 24–31% at 60 °C, 28–35% at 75 °C, and 33–42% at 85 °C, corresponding to moisture losses of 42–63%, 45–68%, and 58–71%, respectively.

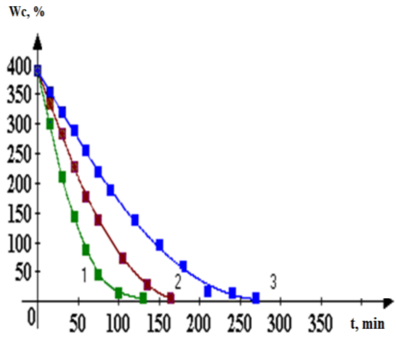
The efficiency of the first drying period is determined by the structure of the product layer (thickness, porosity, particle distribution) and the intensity of contact between the product and the drying agent, associated with a reduction in the thickness of the boundary layer and an intensification of heat transfer. The simultaneous increase in temperature and air velocity leads to the extension of the first period and the intensification of initial evaporation, in which 42–71% of the total moisture is removed, confirming the decisive role of air flow parameters on the drying kinetics of apple pomace.

In the second period, characterized by a decrease in the drying rate, moisture reduction is limited by internal diffusion processes. As the water content decreases, the energy required to bind moisture to the solid matrix increases, and transfer occurs predominantly through vapor diffusion through the dry layer, whose thickness progressively increases (Acevedo et al., 2006).

The analysis of drying kinetics showed that the second period corresponds to different moisture content intervals, influenced by air flow parameters. To characterize this stage, the average drying rate ($(\Delta W/\Delta\tau) = (W_{cr}^{u}-8)/(\tau_f-\tau_{cr})$was used, whose values, depending on the experimental conditions, are shown in Fig. 3.17. Fig. 3.17 shows that moisture evaporation in the second drying period of apple pomace is determined by air temperature and is practically independent of air velocity. A higher temperature results in a greater driving force for heat exchange and promotes the redistribution of internal moisture, which is the factor that determines the drying rate in this phase. The study of the influence of product load on the kinetics of the apple pomace drying process was carried out in three series of experiments, changing the initial product load on the drying surface by 6 kg/m^2; 10 kg/m^2; 15 kg/m2 at constant parameters: air temperature 60ºC, 75ºC, 85ºC and air speed 4 m/s (Fig. 3.18-3.20).

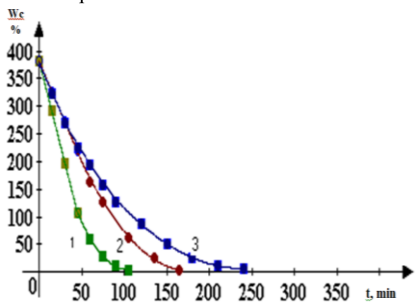


1- 6 kg/m^2; 2- 10 kg/m^2; 3 - 15 kg/m^2
Fig. 3.18 Drying curves for apple pomace at a temperature of 60ºC and different loads.



1- 6 kg/m^2; 2- 10 kg/m^2; 3 - 15 kg/m^2
Fig. 3.19 Drying curves for apple pomace at a temperature of 75ºC and different loads.

Fig. 3.18–3.20 show that both air temperature and product load significantly influence the drying time of apple pomace. Higher temperatures accelerate the achievement of the target moisture content, but at temperatures above 75 °C irreversible reactions and interactions of microelements with oxygen occur, affecting the drying rate. At the same time, a higher load significantly prolongs the total drying time, regardless of the air temperature.



1- 6 kg/m^2; 2- 10 kg/m^2; 3- 15 kg/m^2
Fig. 3.20 Drying curves for apple pomace at a temperature of 85ºC and different loads.

The duration of the drying process, depending on the technological parameters applied, is presented in Table 3.1.

Table 3.1 Duration of the drying process with variable load and temperatures

Drying time, min.	**The load**								
	6 kg/m^2			**10 kg/m^2**			**15 kg/m^2**		
	60°C	75°C	85°C	60°C	75°C	85°C	60°C	75°C	85°C
	120,0	126,0	100,0	255,0	163,0	161,0	325,0	268,0	238,0

Table 3.1 shows an important trend in the drying process, according to which the drying time decreases proportionally with the increase in the temperature of the drying agent. At the same time, at a constant temperature, an increase in the amount of material loaded leads to a direct prolongation of the drying time. Cesco et al. (2023) mention that changing the air temperature during convective drying from 60 to 80°C reduces the drying time by 1.6 times and increases the drying speed by 1.4 times.

Optimal drying at 61°C with a loading density of 0.8 g/cm^3 allows for minimal color change, according to a study conducted using the *Visual Basic* program (Kaur, 2018).

3.3 Development of a mathematical model for the drying process of apple, grape, and tomato pomace

One objective of the research was to establish the dependence of apple pomace moisture content (W) on drying time (τ), air temperature (t), and air flow speed (v). Analysis of the experimental data showed that in the 0–60 min interval, the reduction in moisture content has an approximately linear profile, corresponding to a constant drying rate for each regime. After 60 min, the profile becomes curved, and the drying rate slows down progressively. Both linear and second-order regression equations were determined using *Advanced Grapher* 2.0 and *Microsoft Excel* software, with the exception of regimes with a flow speed of 4 m/s in the 60–255 min segment, for which the models proposed by the software did not sufficiently match the experimental data.

The equations obtained were implemented in *Microsoft Excel*, and based on the calculated values, three-dimensional (3D) graphical representations were generated, illustrating the evolution of drying at air speeds of 2 m/s and 3 m/s, presented in Figs. 3.21 and 3.22. Thus, mathematical models allow the visualization and evaluation of the influence of technological parameters on drying kinetics.

The representation in Fig. 3.21 highlights the mathematical model of drying at an air velocity of 2 m/s, demonstrating the progressive decrease in humidity over time. Air temperature significantly influences the process: at higher values, drying accelerates, confirming the trends characteristic of convective drying.

Fig. 3.22 illustrates the evolution of drying at an air velocity of 3 m/s, showing a more pronounced acceleration of the process compared to the velocity of 2 m/s, which highlights the increased influence of air velocity on mass transfer. The

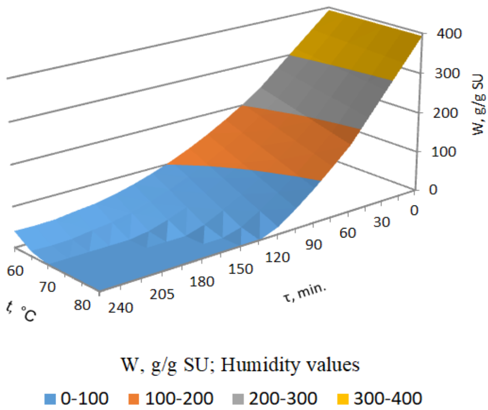


Fig. 3.21 Graphical representation of the mathematical model of drying at a flow speed of 2 m/s

increase in temperature continues to accelerate drying, with the combined effect of temperature and velocity being more noticeable in the initial stages when the product's moisture content is higher.

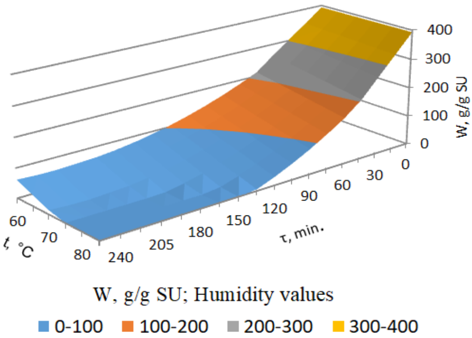


Fig. 3.22 Graphical representation of the mathematical model of drying at a flow speed of 3 m/s

A comparative analysis of Fig. 3.21 and 3.22 shows that increasing the air speed reduces humidity more quickly in the linear phase of the process, and in the nonlinear phase, drying approaches the final value more quickly, especially at favorable combinations of temperature and velocity. The effect of temperature on the total drying time is more pronounced at lower speeds, and at high speeds the additional impact of temperature decreases, indicating an efficiency threshold. These observations highlight the need to adjust the air speed according to the selected temperature and the phase of the process in order to optimize energy consumption and maintain the quality of the final product.

It was found that humidity values decrease intensely in the first phase of the process, and each temperature value corresponds to a time segment where the dehydration phenomenon proceeds according to a second-order regression equation. It has also been demonstrated that regression equations have inversion points, after which the process slows down and humidity values decrease according to other regression equations.

At the same time, calculations were performed for the mathematical model of the drying process, represented mainly by polynomial equations, in which moisture values decrease with increasing duration and temperature. In particular, it was established that exponential equations were identified for drying tomato pomace with infrared radiation, and a higher-order equation was used for convective drying of grape pomace. All the equations were obtained in *Microsoft Excel*, and based on the calculated values, three three-dimensional graphical representations were generated (Figs. 3.23–3.25), illustrating the evolution of the drying process.

Fig. 3.23 illustrates the mathematical model of grape pomace drying by convection, highlighting the decrease in humidity depending on the duration of the process and the air temperature. It can be seen that as the temperature increases, the drying process accelerates, confirming the direct correlation between the air flow temperature and the intensity of dehydration.

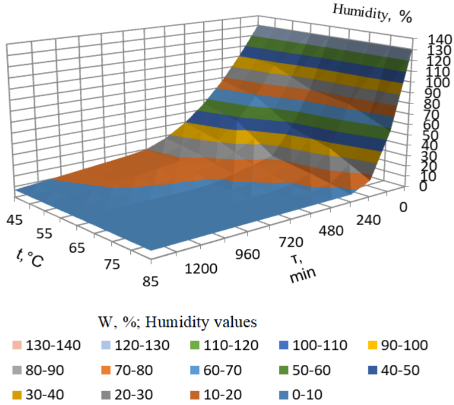


Fig. 3.23 Graphical representation of the mathematical model for the drying process of grape pomace using convection

Fig. 3.24 shows the mathematical model of grape pomace drying by convection combined with infrared radiation (1.33 kW/m²). It has been established that the constant decrease in humidity with the duration of the process, air temperature has a direct impact on the drying rate. The application of infrared waves significantly accelerates dehydration, confirming the general trends of combined drying.

The graph in Fig. 3.25 shows the mathematical model of grape pomace drying using only infrared radiation (100%). Huang (2021) confirms that the use of infrared radiation in the drying process significantly improves drying kinetics, reducing time and energy consumption due to efficient penetration into the product mass. Delfiya et al. (2022) also highlight the advantages of this method in terms of heating uniformity and final product quality, including the preservation of bioactive compounds and natural color.

Fig. 3.25 shows a significant reduction in material moisture as the drying process duration increases. In the combined drying mode, the air flow temperature contributes to intensifying the process by facilitating the transport of moisture from the surface of the material, but the predominant effect is that of infrared radiation, which penetrates the product mass more efficiently and accelerates the drying process compared to conventional methods. The synergy between hot air convection and energy transfer through

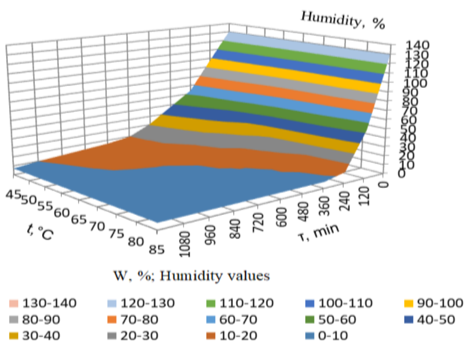


Fig. 3.24 Graphical representation of the mathematical model of the process of drying grape pomace by convection + infrared waves (1,33kWt/m^2)

infrared radiation results in a significant reduction in drying time and increased energy efficiency. At higher temperatures, the rate of moisture reduction is accelerated, confirming the superior efficiency of infrared radiation in dehydration processes. The drying method significantly influences the dynamics of moisture reduction in grape pomace. It has been established that the exclusive use of convection leads to a slower drying process, while the combination of convection with infrared radiation significantly accelerates moisture reduction.

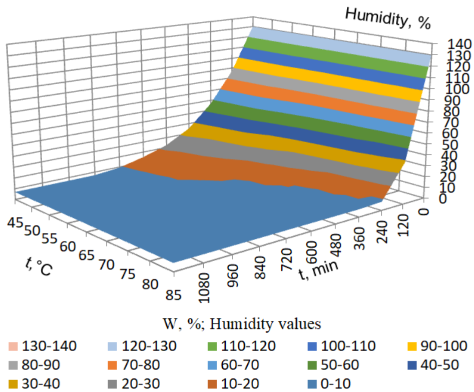


Fig. 3.25 Graphical representation of the mathematical model of the drying process of grape pomace by convection + infrared waves (2.0kWt/m^2)

The most effective method has proven to be drying using 100% infrared radiation, which allows for a rapid and uniform reduction in the moisture content of the material. Thus, infrared radiation is a promising technology for optimizing the drying process of grape pomace, reducing the time required and improving energy efficiency.

3.4 The influence of thermal factors on the quality of apple and grape pomace during the drying process

During fruit processing, complex chemical reactions occur, causing browning, manifested by the formation of colored compounds ranging in color from yellow-brown to black. These changes are due to Maillard reactions, caramelization processes, and enzymatic or non-enzymatic oxidative reactions. (Mi Moon et al., 2020; Bykova et al., 2015). These compounds negatively affect the color, taste, and aroma of the product, which is why the browning index is used as an indicator of the quality of dried pomace. The intensity of browning depends on temperature, drying time, moisture content, oxygen, enzymatic activity, and substrate availability. The maximum permissible temperature of the product is the main criterion in choosing the drying regime, influencing the efficiency of the process and the final quality (Petrescu et al., 2019). The evaluation of the thermal action and the weighted temperature allows the comparison of the efficiency of different regimes and the analysis of changes in the substances in the product.

To determine the thermal load and the weighted temperature, the graphical relationships between the temperature of apple pomace and the duration of the convective drying process, presented in Figs. 3.26–3.28, were used.

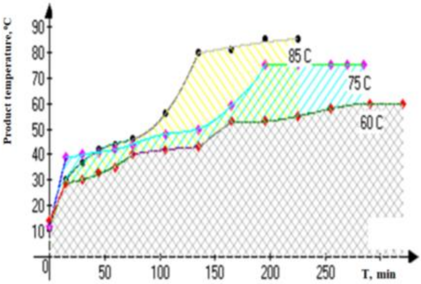


Fig. 3.26 Dependence of apple pomace temperature on drying time at a constant speed of V=2m/s and various air temperatures, ^{0}C: 60, 75, 85

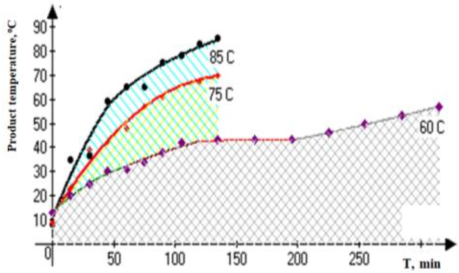


Fig. 3.27 Dependence of apple pomace temperature on drying time at a constant speed of V=3 m/s and various air temperatures, ^{0}C: 60, 75, 85

The analysis in Fig. 3.26–3.28 shows that the product temperature rises rapidly in the first minutes of drying, then the heating rate gradually decreases, and towards the end the product temperature approaches that of the drying air.

The results obtained indicate that the weighted temperatures reflect the combined influence of temperature and duration on the browning index of apple pomace,

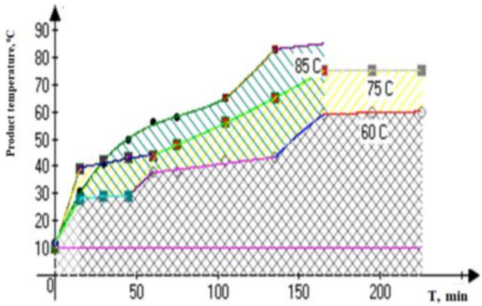


Fig. 3.28 Dependence of apple pomace temperature on drying time at a constant speed of V=4m/s and various air temperatures, ^{0}C: 60, 75, 85

which increases linearly with temperature. This correlation allows for the evaluation and optimization of browning, ensuring that the quality of the final product is maintained (Li et al., 2023).

The analysis in Fig. 3.29 shows that as the speed and temperature of the drying air increase, the browning index of apple pomace decreases, and the rate of this decrease becomes more pronounced at lower speeds of the drying agent. This trend indicates that enzymatic browning reactions may occur during the drying process, caused by favorable temperature and humidity conditions.

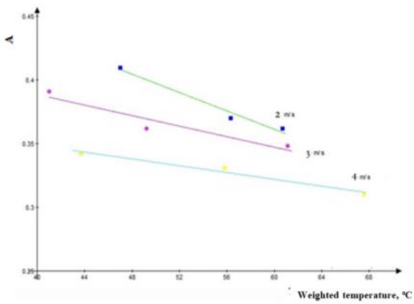
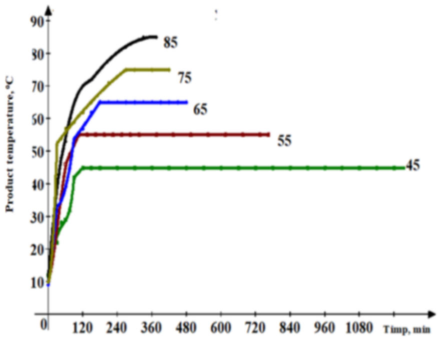


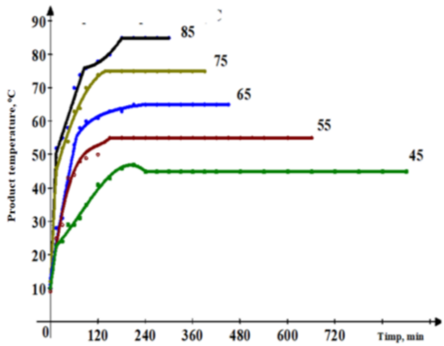
Fig. 3.29 Variation of the browning index as a function of weighted temperature

Analysis of the browning index shows that as the speed and temperature of the drying air increase, its value decreases, and the decrease becomes more pronounced at lower speeds. This evolution reflects the enzymatic browning reactions, favored by optimal temperature and humidity conditions, in which the polyphenol oxidase enzyme oxidizes the polyphenols in apples through interaction with atmospheric oxygen, a phenomenon confirmed by Petrescu et al. (2019).

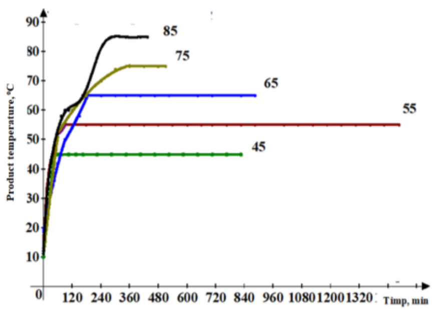
Fig. 3.30 shows the variation in grape pomace temperature during drying at different air temperatures, comparing three methods: a) convective drying; b) combined convective drying + IR radiation 2.0 kW/m²; c) combined convective drying + IR radiation 1.33 kW/m².



a)



b)



c)

Fig. 3.30 Evolution of grape pomace temperature during the drying process for three drying methods: a) convective; b) combined (convection + IR 2.0 kW/m²); c) combined (convection + IR 1.33 kW/m²) at different air temperatures

The graphical dependencies obtained were used to calculate the thermal load on the product and the weighted average temperature of the product for the entire drying process period.

A comparative analysis of drying methods (Fig. 3.31) shows that combined methods significantly reduce the browning index compared to traditional convective drying, with maximum browning values recorded at 45°C and approximately 70°C. These results are obtained by Heras-Ramírez et al. (2011), who showed that high temperatures reduce polyphenols and flavonoids, intensifying browning, while combined methods, such as blanching followed by drying at moderate temperatures, preserve product quality and bioactive compounds.

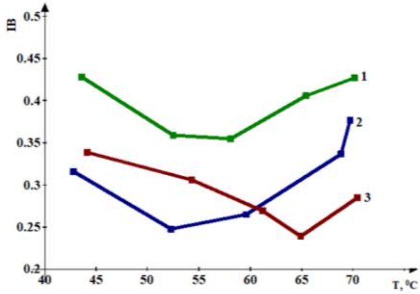


Fig. 3.31 Change in browning index values depends on the weighted average temperature of the product during grape pomace dehydration, using different drying methods:
1) convective;
2) combined: convection + IR 2.0 kW/m2;
3) combined: convection + IR 1.33 kW/m2.

Combined drying is an effective strategy for optimizing the process, reducing browning, and maintaining the nutritional properties of apple pomace. Browning at low temperatures results mainly from the activity of oxidative enzymes, favored by slow moisture removal, insufficient temperatures for enzyme inactivation, and the effects of infrared radiation.

As the drying temperature and product temperature increase, moisture reduction accelerates, the period favorable for oxidative enzymatic reactions shortens, and enzymatic activity is inhibited. At higher temperatures and low moisture content, amino-carbonyl reactions, non-enzymatic oxidation, and caramelization are triggered. Higher IR radiation intensity can lead to local overheating of the product, especially when the moisture content is low, thus accelerating the drying process.

4. DEVELOPMENT OF MANUFACTURING TECHNOLOGIES FOR HEALTHY FOOD PRODUCTS BASED ON LOCAL RAW MATERIALS

4.1 Development of manufacturing technologies for extruded food products based on cereal crops and canning industry waste

Research into extruded food products plays a key role in the development of a healthy and varied diet. It aims to expand the range of products made from local raw materials, especially cereals, while also making use of agri-food waste. The extrusion process makes it possible to obtain products with increased shelf life, which are easy to consume and have high nutritional value.

A major objective is to diversify extruded cereal products by fortifying them with functional ingredients: dietary fiber, vitamins, unsaturated fatty acids, minerals, probiotics, and prebiotics to improve their nutritional value (Iușan, 2023). In this context, it is necessary to establish clear standards for fiber content, given that products with a minimum of 3 g/100 g are considered good sources, and those with more than 6 g/100 g are rich in fiber. Compliance with these requirements is regulated by Moldovan legislation on food labeling (Mihu, 2012; Iușan et al., 2022).

Recipes for extruded products are developed in accordance with regulatory documentation and food safety standards, aiming for compositional balance and technological innovation. In general, research in this field contributes to the production of nutritious and affordable products that support the long-term health and well-being of consumers.

In the Republic of Moldova, research in the field of nutrition focuses on the complete use of agricultural raw materials and the reduction of technological losses, with the aim of increasing economic efficiency and promoting sustainable consumption (Nicolaeva et al., 2004). An innovative area of research is the development of extruded food products from cereal raw materials and waste from the fruit and vegetable canning industry. The extrusion process allows these secondary resources to be transformed into functional products with high nutritional and biological value, while contributing to environmental protection and food diversification. In order to make efficient use of vegetable waste in the extrusion process, the drying process of secondary raw materials (apple, grape, and tomato pomace) has been optimized in terms of temperature and air flow rate.

Based on powders obtained from apple, tomato, and grape pomace, recipes were developed for extruded products using local raw materials: corn type no. 394—in variable combinations, according to the following schemes:

1. 100% corn (control);
2. 90% corn + 10% apple pomace powder;
3. 80% corn + 20% apple pomace powder;
4. 95% corn + 5% tomato pomace powder;
5. 85% corn + 15% tomato pomace powder;
6. 90% corn + 10% grape pomace powder (Sauvignon);
7. corn 80% + 20% grape pomace powder (Codrinschii).

During the development process, calculations were made for the dietary fiber content and the extrusion parameters were optimized, identifying the technological conditions that maximize the efficiency of the process. The moisture content of the raw material proved to be critical for the formation of the extruded product structure, influencing the degree of expansion and the final texture. The optimal moisture content of the mixtures was established between 15 and 16%, which allows for a porous, crunchy, and homogeneous structure.

The extruder was preheated to 140–150°C, and the actual processing temperature ranged from 90 to 120°C, depending on the proportion of plant waste, which influences thermal conductivity and heat transfer efficiency. The processing time was between 13 and 20 s, and the working pressure varied between 24 and 30 atm. After extrusion, the products were gradually cooled to 18–20°C to stabilize their physicochemical properties and prevent structural changes, and were then packaged in hermetically sealed polyethylene bags to maintain quality and freshness.

The application of the differentiated quality assessment method allowed the optimization of the composition, resulting in nutritionally and organoleptically balanced extruded products. The results confirm the efficiency of the developed technology in the valorization of vegetable waste and its relevance for the sustainable development of the food industry in the Republic of Moldova. The study of the physicochemical indices of the obtained products revealed optimal parameters that influence the technological properties, nutritional value, structural stability, and water and oil retention capacity, facilitating the production of products with optimal functional and sensory characteristics.

Table 4.1 Physical and mechanical properties of extruded products based on cereal raw materials and waste from the canning industry

No.	Extruded product name	Humi-dity, %	The coefficient				Organo-leptic score*
			infla-tion	water reten-tion	oil reten-tion	expan-sion	
1	Corn type no. 394 (control)	6.3	4.60	4.30	1.00	3.80	4.90
2	Corn type no. 394 + 10% apple pomace powder	6.35	4.10	3.80	0.95	3.50	4.80
3	Corn type no. 394 + 20% apple pomace powder	6.20	4.40	3.95	1.00	3.30	4.90
4	Corn type no. 394 + 5% tomato pomace powder	5.95	3.95	4.05	0.85	3.70	4.50
5	Corn type no. 394 + 15% tomato pomace powder	6.00	4.30	4.95	0.95	3.60	4.30
6	Corn type no. 394 + 10% Sauvignon grape pomace powder	6.60	4.25	3.90	1.00	3.50	4.40
7	Corn type no. 394 + 20% Sauvignon grape pomace powder	6.75	4.60	4.00	1.05	3.20	4.35
8	Corn type no. 394 + 10% Codrinschii grape pomace powder	6.40	4.05	4.00	0.95	3.40	4.40
9	Corn type no. 394 + 20% Codrinschii grape pomace powder	6.50	4.45	4.10	1.00	3.20	4.30
* - NOTE – Organoleptic score max 5.0 points.							

The analysis of the data presented in Table 4.1 highlights the variations in the physical and mechanical coefficients of the extruded products depending on the composition of the mixtures. The expansion coefficient varied between 3.20 and 3.70, reaching maximum values when 10% tescovine powder was added, which indicates high porosity. At higher powder concentrations (20%), expansion decreased, reflecting the influence of plant fibers on the product structure. The swelling coefficient ranged between 3.95 and 4.60, showing a slight increase in mixtures with 20% tescovin, due to the different ability of the fibers to retain moisture and interact with the starch matrix during extrusion.

Water retention capacity ranged between 3.80 and 4.30, increasing by 3–5% with increasing pomace proportion, which highlights a more intense interaction between hydrophilic and hydrophobic components. The oil retention coefficient (0.85–1.05) increased by approximately 5% with the addition of 20% pomace, correlated with the structure of the fibers and their degree of porosity.

The results confirm that the addition of pomace significantly influences the physical and mechanical properties, improving the water and lipid retention capacity and increasing the functional value of extruded products. The determination of the nutritional value (Tables 4.2–4.4) revealed a high content of dietary fiber and an enrichment in macronutrients and bioactive compounds, demonstrating the efficiency of utilizing plant waste to obtain products with an enhanced nutritional profile.

Table 4.2 Biological value of extruded products based on cereal raw materials and tomato pomace waste per 100 g.

No.	Name of indices	Extruded product made from 95% corn type no. 394 + 5% tomato pomace powder	Extruded product made from 85% corn type no. 394 + 15% tomato pomace powder
1	Protein, %	11,10±0,02	12,30±0,01
2	Fat, %	5,03±0,08	6,60±0,01
3	Carbohydrates,%, including: dietary fiber	70,41±0,01 10,84±0,02	67,60±0,01 14,10±0,01
	Vitamins, mg		
4	Vitamin B_1	0,38±0,03	0,37±0,1
5	Vitamin B_2	0,10±0,02	0,13±0,01
6	Tocopherols, including	8,02±0,11	24,03±0,08
7	α-tocopherols	6,30±0,02	18,91±0,01
8	Carotenoids, including	5,63±0,02	16,96±0,02
9	β-carotene	0,37±0,02	1,13±0,01
10	lycopene	0,60±0,02	1,80±0,01
	Macronutrients, mg		
11	K	350,07±1,18	419,75±0,73
12	Ca	60,72±0,05	114,80±0,01
13	Si	47,60±0,02	53,20±0,02
14	P	246,51±0,03	276,00±0,09
15	Mg	11,74±0,01	87,20±0,01
	Microelements, mg		
16	Fe	3,27±0,02	3,47±0,01
17	Zn	0,23±0,03	0,69±0,01
18	Mn	0,93±0,01	1,12±0,02
19	Se	8,31±0,02	24,69±0,02

The analysis of extruded products obtained from mixtures of corn (85%) and tomato pomace powder (15%) showed a significant increase in the biological value of the product (Table 4.2). This improvement is due to the high content of bioactive compounds in tomato pomace, especially dietary fiber and carotenoids, which give the product functional properties and beneficial effects on health. The results obtained are consistent with those reported by Brighina et al. (2024), who identified high concentrations of lycopene, β-carotene, and dietary fiber in tomato pomace, as well as with the studies by Yagci et al. (2022), which demonstrated that adding it to extruded products increases the content of phenolic compounds and lycopene. Thus, the use of tomato pomace as a functional ingredient is an effective solution for enriching the nutritional and bioactive value of extruded products, while maintaining their optimal technological properties.

To highlight the effect of grape pomace on the biological value of extruded products, cereal mixtures enriched with this by-product were analyzed, and the results are presented in Table 4.3.

Table 4.3 Biological value of extruded products based on cereal raw materials and grape pomace waste per 100 g.

No.	**Name of indices**	**Extruded product made from 90% corn type no. 394 + 10% Sauvignon grape pomace powder**	**Extruded product made from 80% corn type no. 394 + 20% Sauvignon white grape pomace powder**	**Extruded product made from 90% corn type no. 394 + 10% Codrinschii red grape pomace powder**	**Extruded product made from 80% corn type no. 394 + 20% Codrinschii red grape pomace powder**
1	**2**	**3**	**4**	**5**	**6**
1	Protein, %	14,43±0,09	9,93±0,01	10,30±0,01	9,37±0,01
2	Fat, %	5,40±0,02	6,64±0,01	5,50±0,01	7,03±0,08
3	Carbohydrates, %, including: dietary fiber	68,50±0,02 11,00±0,16	65,90±0,01 13,81±0,01	68,40±0,01 11,20±0,01	65,81±0,01 14,21±0,01
	Vitamins, mg				
4	Vitamin B1	0,30±0,02	0,26±0,08	0,30±0,01	0,28±0,04
5	Vitamin B2	0,09±0,01	0,08±0,01	0,07±0,01	0,08±0,02
6	Vitamin B4	63,91±0,04	56,58±0,52	58,21±0,01	65,02±0,09
7	Vitamin B5	0,55±0,01	0,49±0,10	0,51±0,01	0,51±0,01
8	Vitamin B6	0,36±0,02	0,33±0,04	0,39±0,02	0,41±0,03
9	Vitamin H	19,81±0,09	17,61±0,01	21,10±0,13	20,10±0,01
10	Vitamin K	0,27±0,13	0,25±0,02	0,25±0,02	0,24±0,03
11	Vitamin PP	2,78±0,01	2,50±0,01	2,41±0,01	2,50±0,02
	Macronutrients, mg				
12	K	314,52±0,04	309,04±0,05	323,03±0,08	326,06±0,08
13	Ca	13,51±0,02	27,00±0,12	18,51±0,01	37,10±0,13
14	Mg	100,51±0,04	101,12±0,04	104,35±0,05	108,53±0,09
15	P	285,21±0,04	270,48±0,04	288,03±0,08	276,0±0,14
16	Si	45,93±0,03	41,02±0,1	45,91±0,01	40,81±0,01

Table 4.3 (continued)

1	2	3	4	5	6
	Microelements, mg				
17	Fe	4,42±0,02	5,13±0,01	4,36±0,01	5,64±0,02
18	Co	4,43±0,02	3,93±0,01	4,40±0,01	3,91±0,01
19	Cu	252,08±0,09	224,05±0,07	252,08±0,09	230,03±0,08
20	Se	24,30±0,01	21,60±0,03	24,30±0,01	21,81±0,01

Analysis of the data in Table 4.3 indicates that the addition of grape pomace powder from red and white grapes does not contribute to a significant increase in the biological value of extruded products, but it does improve their nutritional profile by providing valuable bioactive compounds.

The incorporation of 20% grape pomace into extrusion mixtures resulted in products with a higher content of dietary fiber and phenolic compounds, confirming the observations of Fontana et al. (2013) on the increase in fiber and antioxidant content and those of Altan et al. (2008) on the improvement of nutritional value and oxidative stability. Therefore, the use of grape pomace in extrudates is a sustainable solution for the valorisation of grape pomace and the development of foods with enhanced functional properties.

Next, to assess the influence of other types of plant material on the biological value of extruded products, the impact of adding apple pomace was analyzed, with the results presented in Table 4.4.

Table 4.4 Biological value of extruded products based on cereal raw materials and apple pomace waste per 100 g.

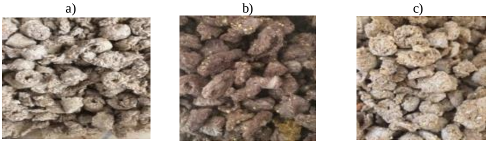
No.	**Name of indices**	**Extruded product made from 90% corn type no. 394 + 10% apple pomace**	**Extruded product made from 80% corn type no. 394 + 20% apple pomace**
1	**2**	**3**	**4**
1	Protein, %	9,54±0,02	8,56±0,01
2	Fat, %	3,82±0,01	3,55±0,01
3	Carbohydrates, % including: dietary fiber	67,12±0,03 9,48±0,01	62,58±0,03 8,56±0,01
Vitamins, mg			
4	Vitamin B_1	0,36±0,01	0,32±0,01
5	Vitamin B_2	0,12±0,01	0,10±0,01
6	Vitamin B_4	63,91±0,01	56,83±0,08
7	Vitamin B_5	0,51±0,01	0,44±0,01
8	Vitamin B_6	0,29±0,01	0,26±0,01
9	Vitamin E	1,08±0,91	0,11±0,01
10	Vitamin PP	2,71±3,87	1,41±0,01
Macronutrients, mg			
11	K	308,41±0,01	376,80±0,13
12	Mg	85,21±0,01	78,31±0,01
13	P	263,13±0,08	236,20±0,01
14	Si	50,41±0,01	44,81±0,01

Table 4.4 (continued)

1	2	3	4
Microelements, mg			
15	Fe	2,94±0,01	2,67±0,01
16	Co	4,60±0,01	4,09±0,01
17	Cu	261,93±0,08	363,71±0,02
18	Se	26,12±0,04	23,21±0,02
19	Mn	0,88±0,01	0,78±0,00

Analysis of the data in Table 4.4 shows that extruded products obtained from cereal raw materials and apple pomace powder have a high dietary fiber content, thus falling into the category of fiber-rich products with beneficial effects on consumer health. For the efficient use of raw materials and waste from the fruit and vegetable canning industry, a complete technological scheme has been developed, which includes the following stages: preparation and obtaining mixtures, extrusion, cooling, and packaging, ensuring a sustainable and quality-controlled process. The developed technological scheme offers an effective solution for obtaining innovative extruded products with increased nutritional value and reduced environmental impact, in accordance with the observations of Altan and Maskan (2011) and Foschia et al. (2013), which highlight the potential of extrusion in the development of sustainable functional foods. The implementation of this technology at the companies "Policom-Prim" SRL, "Biocom" SRL, "Triodor" SRL, and "Randuel" SRL has enabled the manufacture of extruded products with a high content of fiber and bioactive compounds, while maintaining optimal nutritional and technological quality. The experimental samples obtained under industrial conditions are presented in Fig. 4.1.

a) b) c) **d)** **e)** **f)**



g) **h)** **i)**

Fig. 4.1 Samples of extruded products based on cereal raw materials and waste from the fruit and vegetable canning industry:

NOTE: a) Extruded product made from corn type no. 394 + 10% apple pomace powder; b) Extruded product made from corn type no. 394 + 20% apple pomace powder; c) Extruded product made from corn type no. 394 + 5% tomato pomace powder; d) Extruded product made from corn type no. 394 + 15% tomato pomace powder; e) Extruded product made from corn type no. 394 + 10% Sauvignon grape pomace powder; f) Extruded product made from corn type no. 394 + 20% Sauvignon grape pomace powder; g) Extruded product made from corn type no. 394 + 10% Codrinschii grape pomace powder; h) Extruded product made from corn type no. 394 + 20% Codrinschii grape pomace powder; i) Extruded product made from corn type no. 394.

4.2 Investigation of acrylamide content in extruded products based on cereal raw materials and food industry waste

This study is necessary to describe the mechanism of acrylamide formation in extruded products and to develop effective methods for reducing this harmful substance in food. By establishing the stability of factors such as pH, temperature, pressure, and raw material composition, optimal strategies can be identified to minimize acrylamide formation during food processing. The importance of this study stems from the harmful effects of acrylamide on human health, as it is considered a possible carcinogen and mutagen. By researching different combinations of ingredients and technological conditions, practical solutions can be developed for the food industry, thus contributing to the production of safer foods for consumers.

The results of the study may also have economic and legislative implications, providing scientific support for stricter food safety regulations and the development of innovative technologies in the field of food processing.

Table 4.5 shows the acrylamide content in various samples of extruded products obtained from cereal raw materials with and without the addition of citric acid solution.

Within each category, extruded products manufactured using different recipes and extrusion conditions, including process temperature, were analyzed. Acrylamide concentration was determined in both the base samples and those treated with 3% citric acid solution in order to evaluate the effect of this treatment on reducing acrylamide content. Three percent citric acid was used because this concentration has been shown to be effective in lowering the pH to a level that inhibits the Maillard reaction without adversely affecting the taste, texture, or stability of the product. Higher concentrations can impart an excessive sour taste and alter the structure of the extrudates, while lower concentrations do not provide a significant reduction in acrylamide.

The basic parameters analyzed in the studies include:

1. protein content (g/100 g), which varies depending on the type of raw material used;
2. extrusion temperature (°C), which is an essential factor in the formation of acrylamide;
3. acrylamide concentration (μg/kg) determined by several experimental replicates, with the average value presented;
4. reduction in acrylamide concentration (%) when using citric acid solution (3%).

Table 4.5 Acrylamide content in cereal-based extrudate samples with and without added citric acid solution

No.	Product names	Protein concentration, g/100g	Extrusion temperature, °C	Acrylamide concentration, µg/kg	Acrylamide concentration in products with 3% citric acid solution added, µg/kg	Decrease in concentration in %
1	Corn type no. 394 + 10% apple pomace powder	7,56±0,15	139	119,33±0,75	98,33±0,75	-17,6
2	Corn type no. 394 + 20% apple pomace powder	7,80±0,07	139	135,33±0,75	114,33±0,75	-15,5
3	Corn type no. 394 + 5% tomato pomace powder	7,40±0,04	140	117,33±0,75	94,33±0,75	-19,6
4	Corn type no. 394 + 15% tomato pomace powder	7,75±0,03	140	106,00±1,31	105,00±1,31	-19,2
5	Corn type no. 394 + 10% Sauvignon grape pomace powder	7,78±0,04	140	128,00±1,31	101,33±0,75	-21,0
6	Corn type no. 394 + 20% Sauvignon grape pomace powder	7,92±0,07	140	137,00±1,31	113,00±1,31	-17,5
7	Corn type no. 394 + 10% Codrinschii grape pomace powder	7,64±0,06	140	133,33±1,31	110,33±0,75	-17,3
8	Corn type no. 394 + 20% Codrinschii grape pomace powder	7,80±0,04	140	142,00±1,31	118,33±0,75	-16,9
9	Corn type no. 394	7,43±0,04	139	91,00±1,31	75,67±0,75	-17,6

Analysis of the results obtained indicates that the formation of acrylamide in extruded products depends significantly on the type of raw material, chemical composition, and extrusion process parameters. Products with added vegetable waste had higher acrylamide concentrations than those made from corn, due to their higher content of asparagine and reducing sugars, which promote acrylamide formation reactions (Gökmen, 2012). The application of a 3% citric acid solution led to significant reductions in acrylamide, between 15.5% and 21.0%, due to the decrease in pH and interference with Maillard reactions (Low et al., 2006). These findings suggest that the selection of raw materials, the adjustment of technological parameters, and the use of safe treatments, such as citric acid, can contribute to obtaining extrudates with reduced acrylamide content, while complying with food safety and nutritional quality requirements.

4.3 Investigation of dietary fiber content in extruded products based on cereal raw materials and food industry waste

This research was conducted to improve the enzymatic method for determining the dietary fiber content in extruded products obtained from cereal raw materials and food industry waste.

The proposed method is based on specific enzymatic treatments, adapted to the composition of the raw materials, such as cereals rich in starch and protein or fruits with a high pectin content. This method allows for a clear separation of components and a detailed analysis of the fiber structure, providing data for the nutritional characterization of food products.

The experimental results obtained from the analyses are presented in Table 4.6 and provide a clear picture of the variation in dietary fiber content depending on the type of raw material and the treatments applied. These results reflect the impact of the different processing stages on the fiber composition and allow a detailed evaluation of the effectiveness of the method used.

The results obtained can contribute to the optimization of technological processes for the production of functional foods, supporting the development of products with a balanced fiber content, beneficial for digestive health and metabolism.

Table 4.6 Dietary fiber content in extruded products based on cereal raw materials and food industry waste

No.	Sample names	Mass fraction of fibers, %		Total fiber content, %
		soluble	insoluble	
		pectin+ inulin+ hemicellulose fractions	lignin+cellulose+ hemicellulose	
1	2	3	4	5
1.	Corn type no. 394 + 10% apple pomace powder	3,05±0,01	12,06±0,02	15,11±0,02
2.	Corn type no. 394 + 20% apple pomace powder	4,85±0,04	13,74±0,06	18,59±0,05
3.	Corn type no. 394 + 5% tomato pomace powder	1,58±0,05	11,59±0,05	13,17±0,05
4.	Corn type no. 394 + 15% tomato pomace powder	2,14±0,01	14,13±0,01	16,27±0,01
5.	Corn type no. 394 + 10% Sauvignon grape pomace powder	1,64±0,03	13,13±0,16	14,77±0,02
6.	Corn type no. 394 + 20% Sauvignon grape pomace powder	2,15±0,06	16,28±0,03	18,43±0,05
7.	Corn type no. 394 + 10% Codrinschii grape pomace powder	1,75±0,01	13,54±0,03	15,29±0,02

Table 4.6 (continued)

1	2	3	4	5
8.	Corn type no. 394 + 20% Codrinschii grape pomace powder	2,25±0,01	13,82±0,08	16,07±0,05
9.	Corn type no. 394.	1,23±0,01	10,30±0,02	11,53±0,02

The analysis of the dietary fiber composition in extruded products highlights the influence of the type of raw material and the addition of food industry by-products on the fiber content and structure. Extruded products made from corn type No. 394 had a fiber content between 11.53% and 18.59%, with higher values associated with the addition of apple or grape pomace, which enrich the fiber profile, especially insoluble fibers (Kauser et al., 2021). The extrusion process can modify the structure of the fibers, increasing their solubility and thus influencing the nutritional characteristics of the final product (Li et al., 2020). These results highlight the potential of utilizing food by-products in the development of extruded products with an improved nutritional profile, contributing to the production of functional foods tailored to consumer requirements.

5. MATHEMATICAL MODELING AND ANALYSIS OF THE TECHNOLOGICAL FEASIBILITY OF THE EXTRUSION PROCESS FOR GRAIN-BASED RAW MATERIALS

The mathematical model applied in this research plays an essential role in the complex evaluation of product quality, providing the possibility of a detailed and objective analysis of the main quality indicators. The differentiated evaluation method involves comparing the analyzed products with a benchmark model in order to determine the degree of compliance with established standards and the individual deviations of the indicators from the reference values.

5.1 Modeling of the extrusion process to optimize technological parameters

The integrated assessment method considers weighting coefficients, which allows for the standardization of results and comparability between products with different characteristics. Thus, the quality of a product is expressed by a generalized indicator (Pi), located within an interval from 0 to 1, where the maximum value indicates a high-quality product.

To optimize the quality determination process, the Brandon method was used. This method allows for the formulation of a mathematical relationship between the product quality and the essential influencing factors: temperature, pressure, time, and mixture moisture.

This non-linear relationship is validated using statistical criteria, such as the Fisher criterion, to ensure the compatibility of the mathematical model with the experimental data. If the model meets the established statistical conditions, it can be used confidently in the analysis and optimization of product quality. Based on this method, mathematical models for different types of raw materials were calculated, which are presented in Table 5.1.

Table 5.1 Extruded products based on cereal raw materials and waste from the vegetable and fruit canning industry

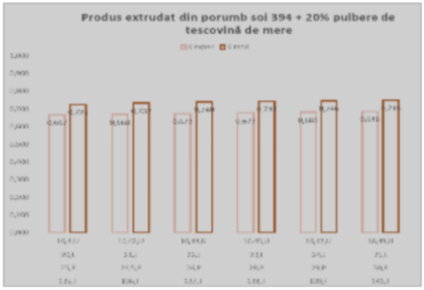
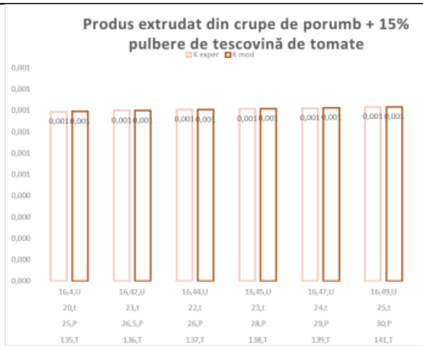
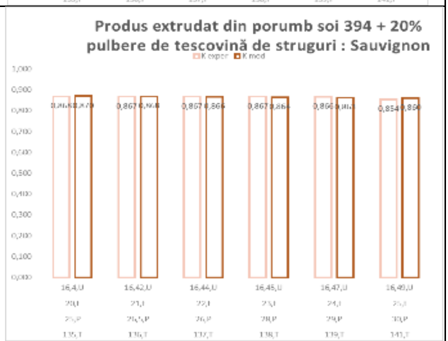
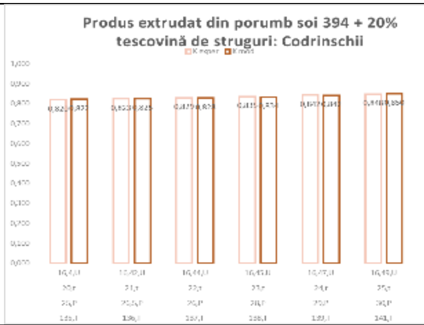
No.	Product name	The mathematical model	Similarity of the mathematical model to the quality coefficient
1	**2**	**3**	**4**
1	Extruded product from corn type no. 394/apple pomace powder, 80/20	$K_{extruded\ corn\ 394/apple,80/20} = 0,675 * (0,0018 \cdot T + 0,8014) * (0,0006 \cdot P + 0,9857) * (0,0006 \cdot t + 0,9905) * (-0,0069 \cdot U + 1,1051)$	
2	Extruded product from corn grits/tomato pomace powder, 85/15	$K_{extrudedcorn,tomato,}85/15 = 0,805 * (0,0055 \cdot T + 0,4392) * (-0,0002 \cdot P + 1,0012) * (-0,0003 \cdot t + 1.006) * (0,0135 \cdot U + 0,7971)$	
3	Extruded corn product type no. 394 / grape pomace powder: Sauvignon, 80/20	$K_{extruded\ corn\ 394/Savignon,}20 = 0,865 * (-0,0012 \cdot T + 1,1417) * (-0,0008 \cdot P + 1,0201) * (0,0008 \cdot t + 0,984) * (0,004 \cdot U + 0,9386)$	

Table 5.1 (continued)

1	2	3	4
4	Extruded corn product type no. 394 / grape pomace: Codrinschii, 80/20	$K_{extruded\ corn\ 394/\ .Condrinsc} /20 = 0{,}833 * (\ \ 0{,}0033 \cdot T + 0{,}6358) * (\ \ 0{,}0007 \cdot P + 0{,}9856) * (-0{,}0004 \cdot t + 1{,}006) * (\ \ 0{,}0051 \cdot U + 0{,}9207)$	

Similarity criteria are used to assess the degree of agreement between the mathematical model and the experimental data obtained during the raw material extrusion process. These criteria are based on quantitative and statistical analyses, including the application of the Fisher criterion (F), which allows for the evaluation of the significance of differences between the experimental values and those estimated by the model.

The analysis of extruded products based on cereal raw materials and waste from the vegetable and fruit canning industry, presented in Table 5.1, highlights the significant influence of pomace on the texture and moisture of the final product. Specifically, grape pomace contributes to a high similarity of the mathematical model used, due to the presence of polyphenols, which play an important role in stabilizing the extrusion process. Polyphenols have the ability to interact with other components of the raw material, favoring a more uniform and consistent extrusion.

Previous studies support these observations. For example, a study published in *Food Hydrocolloids* highlighted that the addition of grape pomace to cereal and vegetable mixtures can improve the rheological properties of the extruded products, including the stability of the extrusion process and the final product texture (Mironeasa et al., 2021). Another study published in the *Ukrainian Food Journal* demonstrated that the incorporation of grape pomace into corn-based extruded products led to a reduction in the expansion index and the cutting and compression forces, indicating an improvement in the structure and stability of the final product (Mironeasa et al., 2020).

Grape pomace can function as a stabilizing agent in extrusion, contributing to the achievement of products with improved texture and controlled moisture. However, tomato pomace, due to its high acidity content, negatively influences the stability of the process and causes variations in the physico-chemical properties of the final product. These observations highlight the significant impact of waste from the vegetable and fruit canning industry on the behavior of the extrusion process. The mathematical models used for evaluating the quality of extruded products must be adapted to the specific characteristics of each raw material.

5.2 Feasibility study for the manufacturing of extruded food products

The feasibility study on the acquisition and processing costs of raw materials for the production of extruded products was carried out according to Chernykh's (2012) methodology, adapted to the models used in the bakery and confectionery industry, using data updated for the year 2024 from the Ministry of Agriculture and Food Industry (MAIA) and the National Bureau of Statistics (BNS).

Extruded products are obtained from cereal raw materials (corn and sorghum), possibly mixed with vegetable by-products (apple pomace powder), in a processing unit with a capacity of 150 kg of cereals per hour, equipped with specific machinery (Table 5.2).

Table 5.2 Technological equipment required for the manufacture of extruded products

No.	Name of the technological equipment	Consumption of energy resources		Purchase price, lei (y. 2024)
		Water, m^3/h	Electrical energy, kW*h	
1	Magnetic Separator	-	1,50	4592,0
2	Grinding Mill MU-100	-	1,10	2330,0
3	Dryer IT-720	-	1,00	130000,0
4	Homogenizer BF-III	0,2	1,10	3800,0
5	Extruder E-150	-	13,50	192375,0
6	Cutting Machine	-	0,55	2150,0
7	Conveyor belt	-	1,50	8300,0
8	Dryer DKX-III	-	1,50	115000,0
9	Scales	-	-	2000,0
10	Packaging device ED-2	-	0,75	10200,0
	Total cost of technological equipment			470747,0

The estimated direct cost for producing 1 ton of extruded product from sorghum and corn variety no. 394 is 23,501.5 lei, while the addition of 20% apple pomace powder reduces the cost to 13,436.0 lei per ton, reflecting savings in raw materials (Tables 5.3–5.4). The cost structure for the product containing apple pomace is distributed as follows: raw materials 31.26%, packaging and boxes 47.76%, labor 14.88%.

Table 5.3 Estimated cost of material and energy resources for the manufacture of extruded product from soriz and corn type no. 394 (prices y. 2024)

No.	Resource type	Unit of measure	Unit price, lei	1 ton of finished product, consumption rate	Cost	
					lei	%
1	2	3	4	5	6	7
1.	Soriz	tons	20000,0	0,7	14000,0	59,57
2.	Corn	tons	4000,0	0,3	1200,0	5,11
3.	Drinking water	m^3	25,0	2,2	55,0	0,23
4.	Packaging cost	unit.	0,4	9091,0	3718,5	15,82

Table 5.3 (continued)

1	2	3	4	5	6	7
5.	Cardboard boxes	unit.	9,0	300,0	2700,0	11,49
6.	Electricity	kW	3,2	144,0	461,0	1,96
7.	Labor (2 people)	person*h	200,0	6,7	1340,0	5,70
8.	Hygiene materials	kg	100,0	0,27	27,0	0,11
Total estimated direct cost, lei/1 ton					23501,5	

Table 5.4 Estimated cost of material and energy resources for the manufacture of extruded product from corn type no. 394 + 20% apple pomace powder (prices y. 2024)

No	**Resource type**	**Unit of measure**	**Unit price, lei**	**1 ton of finished product, consumption rate**	**Cost**	
					lei	**%**
1.	Soriz	tons	4000,0	0,8	3200,0	23,82
2.	Corn	tons	5000,0	0,2	1000,0	7,44
3.	Drinking water	m^3	25,0	2,7	67,5	0,50
4.	Packaging cost	unit.	0,4	9091,0	3718,5	27,67
5.	Cardboard boxes	unit.	9,0	300,0	2700,0	20,09
6.	Electricity	kW	3,2	225,0	720,0	5,36
7.	Labor (2 people)	person*h	200,0	10,0	2000,0	14,88
8.	Hygiene materials	kg	100,0	0,3	30,0	0,22
`Total estimated direct cost, lei/1 ton					13436,0	

Indirect expenses include the rent of the production unit and equipment depreciation, administrative salaries, and other costs, totaling 1,118 lei per ton (Table 5.5). The total annual cost and estimated selling prices indicate a profitability of approximately 19–20% (Table 5.6). The calculated price per packaged unit (110 g) is 3.14 lei, which ensures competitiveness and affordability on the market.

Table 5.5 Indirect cost structure in the manufacture of extruded products (prices y. 2024)

No	Type of indirect expenses	**Cost value**
1	Rent of premises and technological equipment, lei	130148,4
2	Salary of administrative employees, 12 months, lei	120000,0
3	Administrative and other expenses, lei	45000,0
4	Total indirect cost, lei	295148,4
5	Expected production volume, tons	264,0
	Total estimated indirect cost, lei/ton	1118,0

Also, the total manufacturing costs were determined, proposing a profitability of 19.9% and establishing the sales prices of extruded products (Table 5.6).

Table 5.6 Estimated costs and prices of extruded products (prices y. 2024)

No	Name of economic indices	Products expected to be manufactured	
		Extruded product from soriz and corn type no. 394	**Extruded product from corn type no. 394 + 20% apple pomace powder**
1	Direct cost, lei/1 ton	23501,50	13436,00
2	Indirect cost, lei/1 ton	1118,00	1118,00
3	Total cost, lei/1 ton	24619,50	14554,00
4	Profitability, lei/1 ton	6380,50	3446,00
5	Profitability, %	20,60	19,10
6	Total price, lei/ 1 ton	31000,00	18000,00

This analysis demonstrates the economic feasibility of integrating plant by-products into the manufacture of extruded products, contributing to the optimization of production costs and increasing process efficiency (Chernykh, 2012).

6. SCIENTIFIC JUSTIFICATION AND DEVELOPMENT OF TECHNOLOGY FOR THE PRODUCTION OF DETOXIFYING BIOLOGICALLY ACTIVE FOOD ADDITIVES AND FUNCTIONAL NUTRITION PRODUCTS

6.1 Study of the binding mechanism of lead and cadmium ions to various types of pectin.

The study stands out for its relevance, being motivated by the high level of pollution with heavy metals — particularly lead and cadmium ions — originating mainly from anthropogenic activities such as industry, transport, and agriculture, which pose a significant threat to ecosystems and human health (Commission Report, EU, 2018). Exposure to these metals can affect the central nervous system, kidney function, and immunity. Pectin, through its ability to form stable complexes with lead and cadmium ions, represents a promising approach for reducing toxic effects on the environment and human health.

Research on the interaction between pectins and lead cations has demonstrated that the electrolytic reduction process of lead ions in an aqueous solution of 0.1 mol/L potassium chloride occurs without interference. Increasing the pectin concentration up to 1.0×10^{-4} mol/L, regardless of its degree of esterification, leads to a linear decrease in the intensity of the polarographic wave current, indicating the formation of metal–polysaccharide complexes (Figs. 6.1–6.2). This approach offers promising prospects for the development of effective solutions for environmental detoxification and health protection.

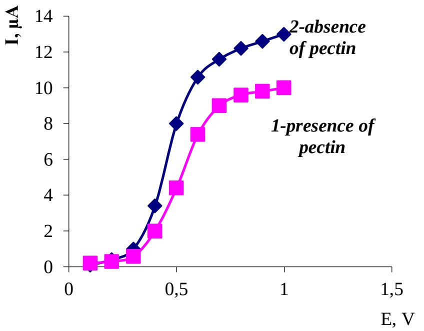


Fig. 6.1 Polarograms of electrolytic reduction of lead ions

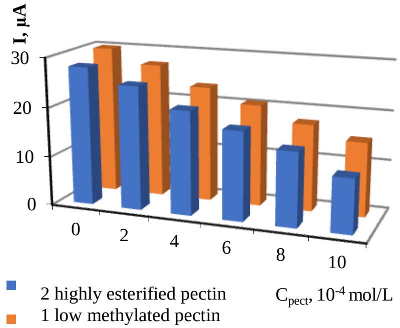


Fig. 6.2 Influence of pectin concentration (Cpect) on the current intensity (I) during lead cation fixation

The results of the study indicate that the formation of the pectin–lead complex occurs at pectin concentrations higher than 7×10^{-4} mol/L, requiring a minimum threshold for initiating the interaction between lead ions and the carboxyl groups of pectin. Only a slight deviation of the half-wave potential ($E_{1}/_{2}$) is observed at ratios 8–10 times higher than the concentration of the lead ion (Table 6.1).

These findings are supported by the scientific literature: pectin forms reversible complexes with heavy metals, influencing the electrochemical properties of the system (Minzanova et al., 2015), and its lead-binding capacity depends on pH and concentration, confirming the existence of a critical threshold required for complexation (Khotimchenko et al., 2007). Thus, the pectin–lead interaction depends both on the polysaccharide concentration and on the chemical conditions of the environment, with significant implications for optimizing electrochemical processes aimed at detecting or removing heavy metals from solutions.

Table 6.1 The value of the potential $E_{1}/_{2}$ of the reduction wave of lead ions as a function of the pectin concentration

$E_{1/2}$, V	***$C_{pect} \cdot 10^{-4}$, mol/L***	***$E_{1/2}$, V***	***$C_{pect} \cdot 10^{-4}$, mol/L***
0,39	1,0	0,39	6,0
0,39	2,0	0,40	7,0
0,39	3,0	0,42	8,0
0,39	4,0	0,45	9,0
0,39	5,0	0,46	10,0

Increasing the lead concentration, in the presence of a constant pectin concentration (1.0×10^{-4} mol/L), causes a linear increase in the height of the reduction wave of lead cations (Fig. 6.3). The deviation from linearity reflects changes in the reversibility of the electrolytic reduction process. The decrease in the wave intensity and the insignificant deviation of the $E_{1}/_{2}$ potential suggest that the pectin–lead complexes do not contribute polarographically actively in the analyzed concentration range.

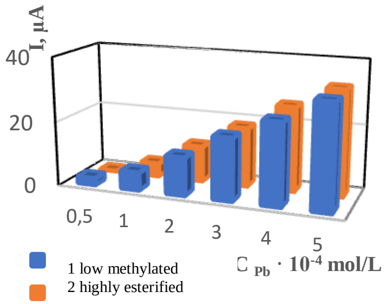


Fig. 6.3 Influence of lead ion concentration (C_{Pb}) on the intensity of the polarographic wave (I) in the presence of pectin

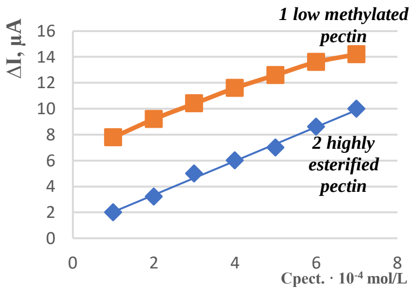


Fig.6.4 Influence of pectin concentration (Cpect) on lead ion fixation

Thus, the decrease in the polarographic wave intensity of lead ions is due to the reduction of their free concentration as a result of complex formation with pectin. The difference between the polarographic wave intensity of free lead ions and that measured in the presence of pectin (I) reflects the degree of lead ion binding by pectins. The analysis of the influence of pectin concentration on the binding of lead ions (I) showed that, regardless of the degree of esterification, an increase in pectin concentration leads to a greater linear increase in binding (Fig. 6.4). Although the degree of esterification has a smaller impact, the results demonstrate that low-methoxyl pectins (LMP) bind lead ions much more efficiently. These conclusions are consistent with previously reported data obtained by potentiometric methods (CSPI, 2016) and dialysis techniques (Codex Stan 118, 1979).

In parallel, the binding of cadmium ions by pectins was also studied, which involved the analysis of the polarographic waves of cadmium ions in an aqueous solution of 0.1 M potassium chloride. The results showed that, within the studied concentration range, the polarographic waves are not affected by interference from other substances. A representative example of a polarogram is shown in Fig. 6.5.

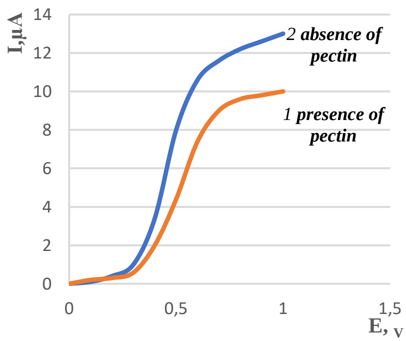


Fig. 6.5 Polarograms of electrolytic reduction of cadmium ions

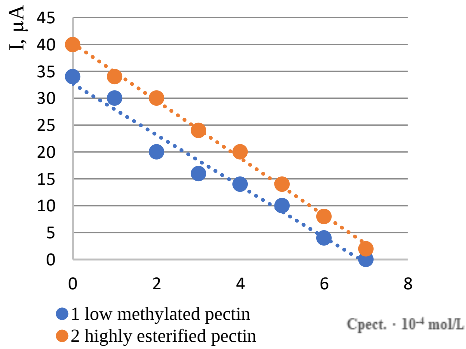


Fig. 6.6 Influence of pectin concentration (Cpect.) on the current intensity (I) of Cd cations (μA)

The obtained results (Fig. 6.5–6.6) indicate that, in the presence of pectin, the reduction current intensity of cadmium cations decreases proportionally to the polysaccharide concentration, suggesting ion complexation and a reduction in their free concentration in solution. This observation is supported by recent studies highlighting the influence of pectin on the electrochemical signals of cadmium and lead, as well as changes in system properties through metal–polysaccharide interactions (Lersanansit et al., 2024; Gołębiowski et al., 2020). The negligible deviation of the $E_{1/2}$ potential, similar to that observed for lead cations, occurs only when the pectin concentration exceeds the cadmium ion concentration by 8–10 times (Table 6.2), confirming the role of pectin as a complexing and electrochemical-stabilizing agent.

Table 6.2 The value of the potential $E_{1/2}$ of the reduction wave of lead ions depending on the pectin concentration

Nr.	**$E_{1/2}$, V**	**$C_{pect.} \cdot 10^4$, mol/l**	**$E_{1/2}$, V**	**$C_{pect.} \cdot 10^4$, mol/l**
1	0,60	1,0	0,60	6,0
2	0,60	2,0	0,60	7,0
3	0,60	3,0	0,62	8,0
4	0,60	4,0	0,65	9,0
5	0,60	5,0	0,67	10,0

The analysis of the obtained data (Fig. 6.7) demonstrates that the fixation of cadmium and lead cations by pectins increases with increasing polysaccharide concentration, the degree of etherification having a more significant impact than the nature of the cation. Low-methoxyl pectins (LMP) fix cadmium ions 1.5–3.7 times more efficiently and lead cations 1.1–1.2 times more efficiently than high-methoxyl pectins (HMP), which is supported in the literature

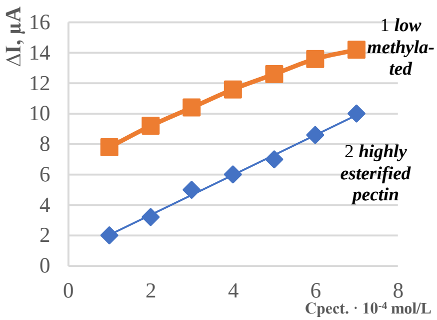


Fig. 6.7 Influence of pectin concentration (Cpect) on cadmium ion fixation

(Khotimchenko et al., 2020; Blaurock-Busch, 2020). This difference is explained by the increase in the number of free carboxyl groups available for cation binding. The results confirm the reliability of the polarographic method for assessing the fixation of cadmium and lead cations by pectins and suggest its applicability in studies on the complex processes of metal fixation in natural environments.

6.2 Investigation of the effect of fruit, vegetable, and medicinal plant components on the binding of lead and cadmium ions to various types of pectin

According to the scientific literature, pectins are frequently used in combination with fruit and vegetable semi-finished products or medicinal plants for the production of biologically active dietary supplements and functional foods (Tutel'yan et al., 2010). In the development of foods with curative or prophylactic effects, there are two main approaches: the first involves incorporating pectin into traditional products such as marmalades, jellies, and juices, but the quantitative and physicochemical limitations of pectin may affect therapeutic efficacy (Tutel'yan, 2001); the second approach involves using pectin in isolated form or combined with other biologically active supplements, as powders, capsules, or tablets, thereby eliminating these constraints (Tutel'yan, 2001; Iușan et al., 2025). The chemical composition of fruits, vegetables, and medicinal plants significantly influences the complexing capacity of pectin, as proteins, phenolic compounds, and organic acids can interact with it, leading to changes in its structural and functional properties (Skurikhin, 1987).

6.2.1 Investigation of the influence of plant raw materials on the fixation of metal ions

Analysis of the influence of juice components on the polarographic waves of cadmium and lead ions indicated that the intensity of the reduction current decreases with increasing juice concentration, highlighting the formation of polarographically inactive complexes (Fig. 6.8).

The cation binding varies linearly depending on the juice content, being maximum for cadmium in the presence of carrot juice and significant for lead in the case of pepper juice. The results confirm that phenolic substances in juices and extracts play an essential role in metal complexation and that the polarographic method can be used effectively to estimate these complexometric processes (Satterfield et al., 2000).

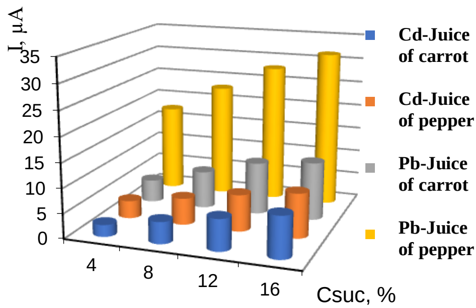


Fig. 6.8 Influence of juice concentration (Csuc.) on the fixation of Pb and Cd (I) ions

The study of triple pectin – metal cation – food systems highlights the existence of variations in the dependence of metal cation binding on pectins. The linear relationship between lead and cadmium binding by PSM and PPE undergoes changes, forming a nonlinear behavior, with a stereotypical pattern (Fig. 6.9-6.13).

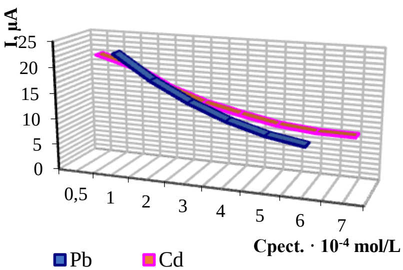


Fig. 6.9 Influence of pectin concentration on the fixation of lead and cadmium (I) ions in the presence of sweet pepper juice

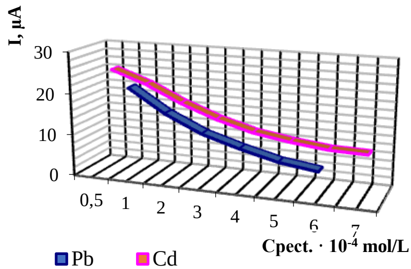


Fig. 6.10 Influence of pectin concentration on the fixation of lead and cadmium (I) ions in the presence of pumpkin juice

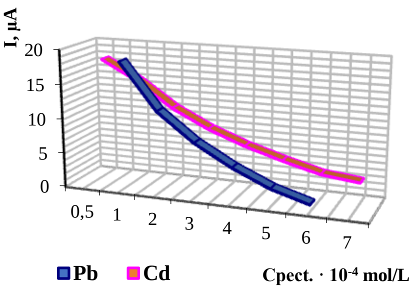


Fig. 6.11 Influence of pectin concentration on the fixation of lead and cadmium (I) ions in the presence of zucchini juice

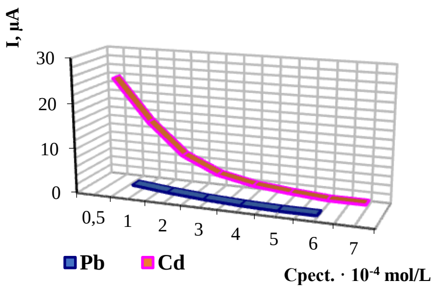


Fig. 6.12 Influence of pectin concentration on the fixation of lead and cadmium (I) ions in the presence of carrot juice

Interactions between pectins and food components, especially phenolics, significantly influence the binding of metal cations in triple systems (Fig. 6.9–6.13). The efficiency of complexation depends on the chemical structure of pectin and the nature of phenolics, with pectin stabilizing metals more efficiently in their presence. Recent studies confirm these observations, showing that interactions with flavonoids and phenolic compounds in dietary fibers increase the binding capacity of metal cations by up to 25–30% in phenolic-rich matrices (Liu et al., 2021; Rocchetti et al., 2022).

Given the nonlinear nature of the influence of pectin concentration on the fixation of lead and cadmium cations, as well as the need for a general assessment of the ability of pectins to fix the examined metal cations, a new concept of the "degree of fixation" of the metal cation with pectin was introduced. The degree of fixation (L, %) is calculated based on the difference between the fixation of metal cations with pectin in the presence of juices and extracts and its fixation in aqueous solution, considered as a reference (tab. 6.3).

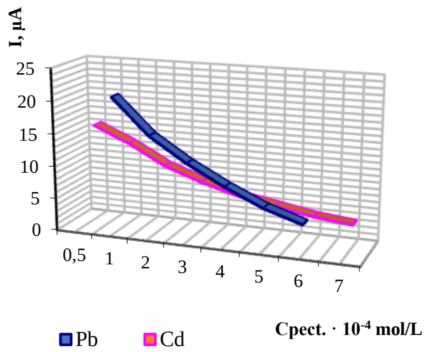


Fig. 6.13 Influence of pectin concentration on the fixation of lead and cadmium (I) cations in the presence of oak extract

Table 6.3 Degree of fixation of lead and cadmium cations with pectins in the presence of juices and extracts

No	Polarized object	Pb^{2+}				Cd^{2+}			
		PPE 1:1	PSM 1:1	PPE 6 :1	PSM 6:1	PPE 1:1	PSM 1:1	PPE 6 :1	PSM 6:1
1	2	3	4	5	6	7	8	9	10
1	Metal + pectin	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00
2	1 + sweet pepper	2,55±0,08	1,41±0,04	1,10±0,04	1,25±0,05	3,71±0,15	1,77±0,09	2,64±0,1 1	1,80±0,09
3	1 + zucchini	1,45±0,04	2,11±0;08	1,18±0,05	1,48±0,05	2,86±0,14	0,89±0,04	1,76±0,07	1,25±0,06
4	1 + pumpkin	0,24±0,002	0,56±0,04	0,75±0,03	0,6±0,03	6,86±0,27	2,94±0,24	3,08±0,09	2,26±0,08
5	1 + plum	0,95±0,02	0,88±0,05	1,08±0,04	0,95±0,04	1,57±0,06	0,55±0,02	1,48±0,06	1,03±0,05
6	1 + sea buckthorn	0,85±0,03 5	0,76±0,04	0,82±0,03	0,94±0,04	3,28±0,16	1,39±0,06	2,44±0,10	1,74±0,07
7	1 + apricot	0,95±0,04	1,06±0,06	0,86±0?03	0,80±0,03	-	-	-	-
8	1 + sour cherry	1,15±0,06	1,18±0,05	1,01 ±0,05	0,92±0,04	-	-	-	-

Table 6.3 (continued)

1	2	3	4	5	6	7	8	9	10
9	1 + black currant	1,40±0,05	1,35±0,06	0,82±0,04	0,69±0,04	-	-	-	-
10	1 + marigold	1,45±0,05	1,76±0,08	1,15±0,05	1,06±0,05	1,43±0,06	0,39±0,02	1,36±0,05	0,86±0,04
11	1 + aronia	1,60±0,05	1,5±0,06	1,15±0,05	0,89±0,04	3,71±0,15	0,50±0,03	2,28±0,08	2,43±0,ll
12	1 + oak extract	1,10±0,04	1,06±0,05	1,03±0,04	1,03±0,05	2,43±0,ll	0,94±0,05	1,92±0,08	1,37±0,06
13	1 + carrots	3,95±0,16	5,41±0,16	1,28±0,05	1,49±0,06	9,43±0,47	3,52±0,09	3,84±0,19	2,77±0,13
14	1 + St. John's wort	1,60±0,06	1,82±0,07	1,21±0,05	1,14±0,05	2,14±0,1 1	0,61±0,03	0,16±0,008	1,23±0,06
15	1 + rosehip	1,05±0,04	1,06±0,05	1,06±0,05	1,0±0,05	1,86±0,09	0,39±0,02	1,48±0,06	0,80±0,04
16	1 + tomato	1,40±0,04	1,65±0,06	1,27±0,05	1,25±0,05	0,29±0,01	0,33±0,02	1,44±0,06	1,03±0,05
17	1 + peaches	0,95±0,05	1,47±0,070	0,91±0,04	0,86±0,04	2,29±0,09	0,44±0,03	1,52±0,07	0,91 ±0,04
18	1 + raspberries	1,85±0,07	1,88 ±0,08	1,21±0,05	1,20±0,05	8,71±0,35	2,55±0,10	3,28±0,16	1,91±0,10

PPE 1:1 - highly esterified pectin (pectin:metal ratio 1:1)
PSM 1:1 - low methoxylated pectin (pectin:metal ratio 1:1)
PPE 6:1 - highly esterified pectin (pectin:metal ratio 6:1)
PSM 1:1 - low methoxylated pectin (pectin:metal ratio 6:1)

The degree of fixation of metal ions by pectins reflects the influence of the components of juices and extracts, phenolic substances being the main factor responsible for this process (fig. 6.14–6.16).

The analysis of the L = f(C_pf) dependencies highlights two ranges: an initial range with a significant increase in fixation at a concentration of 100 mg/L of phenols and a subsequent range with an insignificant effect. In the first range, the degree of fixation depends on the degree of etherification of the pectin and the pectin-metal molar ratio, pectins with low methoxyl content (PSM) showing higher efficiency than those with high content (PPE), which is consistent with the data in the literature (CSPI, 2016; Codex Stan 118, 1979).

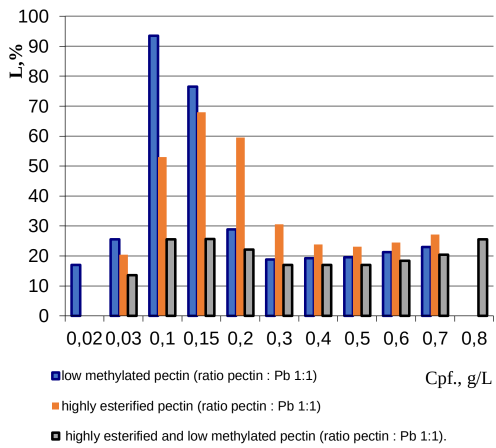


Fig. 6.14 Influence of the concentration of phenolic substances (Cpf) on the degree of lead fixation (L) in the presence of pectins

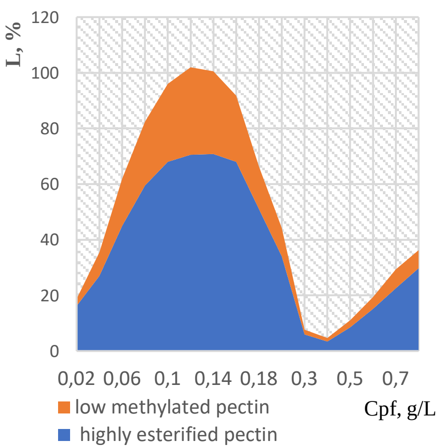


Fig. 6.15 Variation of the degree of fixation of cadmium ions (L) depending on the concentration of polyphenols (Cpf) (pectin:cadmium ratio – 1:1)

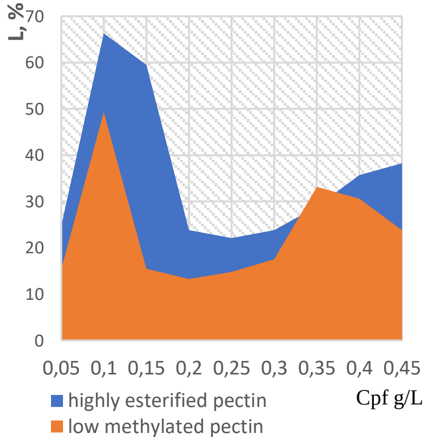


Fig. 6.16 Variation of the degree of fixation of cadmium ions (L) depending on the concentration of polyphenols (Cpf) (pectin:cadmium ratio – 6:1)

Increasing the pectin concentration (pectin:metal ratio 6:1) reduces the maximum binding degree of lead cations in the initial range, while in the subsequent interval the binding becomes independent of the molar ratio and the degree of esterification. Similarly, for cadmium ions, binding increases significantly within the 0–50 mg/L range of phenolic substances, highlighting their influence on the complexometric process (Figs. 6.15–6.16). Low-methoxyl pectins (LMP) exhibit a higher capacity to bind heavy metals compared to high-methoxyl pectins (HMP), due to their free carboxyl groups, which facilitate the formation of stable complexes (Khotimchenko et al., 2017; Sinaki et al., 2024).

The experimental results demonstrate that the binding of lead and cadmium ions by pectins does not strictly depend on the degree of esterification, with cadmium cations being bound more efficiently than lead cations. This suggests the involvement of competing interactions between pectin, phenolic substances, and metal cations, according to the proposed mechanism: formation of metal–pectin complexes (Me^{2+} + Pe → MePe), metal–phenol complexes (Me^{2+} + Pf → MePf), and pectin–phenol complexes (Pe + Pf → PePf). At low phenol concentrations (<100 mg/L) and a pectin–lead ratio of 1:1, lead binding predominates through direct interaction with pectin, while increasing phenol concentration intensifies the pectin–phenol interaction, reducing the binding degree. Furthermore, the pH index significantly influences the process: higher values favor the dissociation of carboxyl groups, increasing binding through ionic interactions, whereas interactions with hydroxyl and phenolic groups may reduce binding efficiency in certain types of pectin (HMP) (Fig. 6.17).

Increasing the pH index reduces the ability of PPE to fix lead cations, increasing the contribution of phenolic substances (reaction 2), a phenomenon highlighted by the decrease in the L value in curves 1–4 in Fig. 6.17. In contrast, PSM maintains a more stable fixation of lead, due to the more stable complexes between carboxylic groups and cations. In the case of cadmium, the complexes with pectins are less stable, and phenolic substances play a dominant role in fixation, contributing 2–8 times more than PPE.

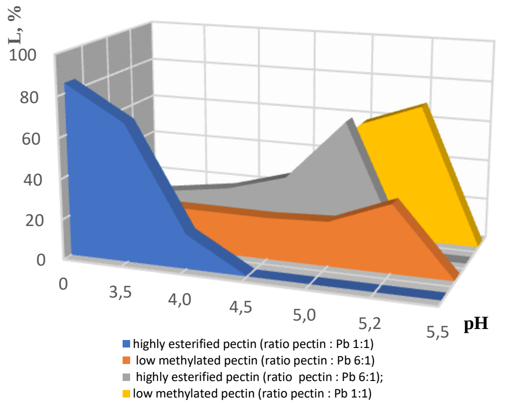


Fig. 6.17 Variation of lead binding capacity by pectin L as a function of pH index

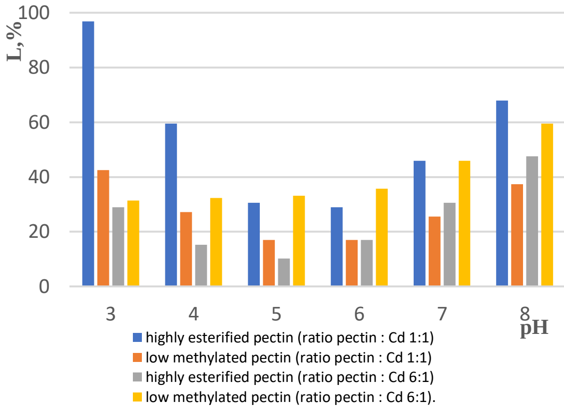


Fig. 6.18 Variation of the Cd^{2+} ion binding capacity by pectin L depending on pH index

Increasing the pectin–cadmium ratio to 6:1 favors the direct interaction of cations with carboxylic groups, reducing the influence of other binding mechanisms and the cumulative effect of phenols. The relatively low stability of the cadmium–PPE complex favors the redistribution of cations to phenolic compounds, while the cadmium – PSM complexes restrict this interaction, which explains the variations observed in the degree of fixation. The saturation of carboxyl groups at high pectin concentrations reduces the number of active sites available for interaction with phenolic compounds, leading to the predominance of the direct binding mechanism mediated by pectin. The chemical characteristics of certain juices and extracts, such as tomato juice or St. John's wort extract, influence the distribution and relative contribution of the binding mechanisms.

Analysis of the data in Fig. 6.18 shows that cadmium binding is strongly dependent on pH, being favored in solutions with pH $\geq$ 2, where interactions with phenolic substances predominate, while the carboxyl groups of pectin play a secondary role (Jakóbik-Kolon et al., 2014; Goncharuk et al., 2023). Unlike cadmium, lead interacts more efficiently with pectin, and the degree of esterification influences cadmium binding more than lead binding. Pectin acts as a polydentate ligand, and the stability of its complexes with heavy metals depends on the nature of the functional groups involved and the competition between ligands. Thus, the polarographic method proves useful in evaluating plant raw materials for the production of biologically active dietary supplements (BADS), functional foods, and products for special nutrition, providing an effective tool for identifying and optimizing chelating agents.

6.3 Justification of the principles for obtaining biologically active food supplements with specified properties

The conducted research has shown that the development of effective biologically active dietary supplements (BADS) requires the creation of products with clearly defined biological properties. However, the scientific literature focuses predominantly on the main ingredient and the role of vitamins, minerals, or phenolic compounds. The results obtained in the study highlight the importance of detailed characterization of the active ingredient, the establishment of optimal doses, and the conditions for use in order to maximize efficacy and reduce potential risks. Combining the active ingredient with other functional components may help control side effects.

The analysis of interactions between pectins, juices, and extracts showed that the presence of additional components can significantly influence the binding capacity of cadmium and lead cations: some substances decrease this capacity, while others enhance it. For example, components in sea buckthorn berries (white sea buckthorn) and pumpkin exhibit an inhibitory effect, unlike carrot juice, which increases the binding degree (Table 6.4).

Table 6.4 Influence of vegetable raw material on the ability of pectin to bind lead cations and cadmium cations

No.	**The effect of the influence of juices and extracts**	**Pb^{2+}**				**Cd^{2+}**	
		1:1		**6:1**		**1:1**	**6:1**
		PPE	**PSM**	**PPE**	**PSM**	**PPE**	**PPE**
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
1	Intensifies fixation	peppers carrots zucchini tomatoes sour cherries blackcurrant chokeberry raspberries marigolds pojarnitsa	peppers carrots zucchini pumpkin tomatoes sour cherries peaches black currants choke berries raspberries marigolds St. John's wort	zucchini carrots tomatoes aronia raspberries marigolds St. John's wort	peppers zucchini carrots tomatoes raspberries	peppers zucchini pumpkin carrots plums peaches chokeberry raspberries buckthorn marigolds oak bark St. John's wort brier	peppers zucchini pumpkin carrots tomatoes plums peaches sea buckthorn chokeberry raspberries rose hips marigolds oak extract

Table 6.4 (continued)

1	2	3	4	5	6	7	8
2	Does not affect fixation	plums apricots oak bark rose hips peaches	apricot oak bark rosehip	pepper plum sour cherry oak bark rosehip	plum buckthorn sour cherry marigold bark bark rosehip	–	–
3	Reduces fixation	pumpkin sea buckthorn	plum sea buckthorn	pumpkin sea buckthorn apricot black currant peaches	pumpkin apricot black currant chokeberry peaches	tomato	St. John's wort

The analysis of the data in Table 6.4 shows that, in order to develop a biologically active dietary supplement (BADS) with predetermined properties, it is very important to evaluate the influence of associated components on the activity of the main ingredient. Compatibility between the active component and the associated ingredients prevents the loss of BADS effectiveness, a principle similar to that applied in pharmaceutical formulation (Ushkalova, 2001). In this context, pectin — known as an effective detoxifying agent — represents a valuable active ingredient, capable of binding and eliminating toxic metals such as lead, copper, cobalt, mercury, cesium, and radioactive strontium without undesirable side effects. The efficiency of pectin depends on its degree of esterification, with low-methoxyl pectin exhibiting superior binding capacity for metal cations.

In BADS formulation, the presence of other plant ingredients may influence this process: combinations with pepper reduce metal binding, whereas blackcurrant, chokeberry, rosehip, raspberry, carrots, zucchini, marigold flowers, and oak extract maintain or increase pectin efficiency. In contrast, ingredients such as pumpkin, white sea buckthorn, plums, apricots, black-fruited rowan, peaches, or tomatoes are unfavorable for the detoxification process. Thus, the fundamental principles for developing pectin-based detoxifying BADS include selecting pectin with suitable physicochemical characteristics, choosing plant raw materials according to their effects on the body, and evaluating the compatibility between pectin and associated ingredients in order to optimize the final product properties.

The research methodology for biologically active dietary supplements (BADS) was developed according to the principles of the document "General Requirements for the Certification of Biologically Active Dietary Supplements," approved by the Ministry of Health of the Republic of Moldova. The experimental studies included determining physicochemical indices (moisture, pectin content, degree of esterification), toxicological analysis (toxic metals, pesticides, microbiological indicators), evaluation of in vitro toxic metal binding capacity, and testing the biological activity of detoxifying BADS through animal experiments and clinical approvals. For these investigations, the PI NIARAVM**,** produced an experimental batch of BADS, which underwent physicochemical analyses, toxicological assessments, and determination of the complexometric capacity of pectin, with the results presented in Table 6.5.

Table 6.5 Physico-chemical and sanitary-hygienic indices of BADS obtained under semi-industrial conditions at NIARAVM

No.	**Index name**	**Control**	**Experimental BADS based on:**	
			pectin and St. John's wort flowers	**pectin and marigold flowers**
	Physico-chemical indices:			
1.	Moisture mass fraction, %	8,2	8,50	7,91
2.	Degree of etherification of pectin, %	23,37	23,37	23,37
3.	Pectin mass fraction, calculated in relation to polyuronides, %	37,15	42,56	56,00
4.	Complexometric capacity, %	75,0	87,50	86,10
	Microbiological indices:			
1.	Aerobic mesophilic and facultative anaerobic microorganisms, CFU/g, max.	$1{,}2 \times 10^4$	$2{,}5 \times 10^2$	$1{,}7 \times 10^4$
2.	Bacteria from the colibacilli group (coliform bacteria)	Absence	Absence	Absence
3.	Pathogenic microorganisms, including *Salmonella*	Absence	Absence	Absence
4.	Yeasts and mold fungi, CFU per 1 g	Absence	Absence	Absence
5.	Mass fraction of metallic impurities (particles), max. 0.3 mm in maximum linear dimension 1%, max.	Absence	Absence	Absence
6.	Toxic chemical elements (mass fraction, mg/kg):			
	lead	2,0	1,0	0,8
	arsenic	3,0	Absence	Absence
	copper	5,0	5,0	5,3
	zinc	5,0-10,0	7,7	7,9
	cadmium	1,0	traces	traces
	mercury	1,0	traces	traces

Clinical evaluation of BADS-detoxifiers was carried out at the Center for Radioactive Medicine in Kiev (Ukraine). Experimental groups were tested on animals exposed to radioactive cesium, and administration of BADS reduced its accumulation by 19–25% compared to the control group. In clinical studies on children from regions affected by radioactive contamination from the Chernobyl Nuclear Power Plant, the inclusion of BADS in the daily diet accelerated the elimination of cesium by approximately 1.5 times compared to the control group, resulting in an average 12.5%

reduction in the level of radioactivity after 21 days. Experts recommend administering BADS in doses of 1–2 g/day for children and 5 g/day for adults, highlighting the effectiveness of the product in reducing the accumulation of cesium and its general therapeutic benefits on the health of the population in contaminated areas.

Following the evaluation of the experimental samples and taking into account the requirements imposed by the normative-technical documentation regarding pectin and the plants used, as well as Government Decision No. 221 of 16.03.2009 on the approval of the Requirements regarding microbiological criteria for food products, BADS quality indices were analyzed, and the results obtained are presented in Tab. 6.6.

Table 6.6 Quality indices of biologically active dietary supplements based on pectin and plants

No.	Index name	Pectin + St. John's wort flowers	Pectin + marigold flowers
1	Consistency	Fresh powder with a fraction of 0.01 mm	Fresh powder with a fraction of 0.01 mm
2	Color	from greenish-brown to brownish-brown	yellowish hue
3	Moisture mass fraction, %, max.	10	10
4	Pectin etherification degree, %, max.	25	25
5	Pectin mass fraction calculated in relation to polyuronides, max.	45	60
6	Metal impurities (particles), max. 0.3 mm in maximum linear dimension 1%, max.	Absence	Absence
7	Aerobic and facultative anaerobic mesophilic microorganisms, CFU/g, max.	$5 \cdot 10^2$	$5 \cdot 10^4$
8	Bacteria from the colibacillus group (coliform bacteria)	1,0	0,1
9	Pathogenic microorganisms, including *Salmonella*	25	25
10	Yeasts and mold fungi, CFU per 1 g	50	100
11	Toxic elements:	Permissible levels, mg/kg, max.	
	Lead	10,0	
	Arsenic	3,0	
	Copper	50,0	
	Zinc	25,0	
	Cadmium	0,05	
	Mercury	0,02	

The quality indices established for the BADS product served as the technical-scientific basis for developing the company standard, which regulates the technological and quality parameters for the production of BADS detoxifying agents.

6.4 Development of functional product compositions and their manufacturing technology

The development of functional products aimed at binding and eliminating toxic metal cations from the body was carried out according to a special technology

(Ugolev, 1991). Functional foods must provide both beneficial effects on the human body and organoleptic characteristics that meet consumer requirements.

The components responsible for the sensory characteristics - taste, smell, color, and texture - of products intended for individuals exposed to toxic metals were obtained by processing plant-based raw materials, specifically fruits and vegetables, according to the data presented in Table 6.7. These components play a crucial role in the organoleptic properties of the products, contributing both to consumer acceptability and to their therapeutic efficacy.

Table 6.7 Physico-chemical indices of pectin-enriched products

No	Name of the product enriched with pectin	Mass fraction of dry substances, at least %	Mass fraction of pectin substances, at least %
1.	Chopped zucchini	14	1,5
2.	Chopped carrots	20	1,5
3.	Chopped sweet peppers with vegetable melange in tomato sauce	14	1,5
4.	Tomato drink	–	0,5
5.	Tomato sauce with fried onions	–	1,5
6.	Tomato sauce with fried onions and carrots	–	1,5
7.	Assorted fruit chips	18–24	1,0
8.	Assorted fruit drinks	10–18	0,5–1,4
9.	Assorted fruit puree	15–18	1,5
10.	Assorted fruit pastes	32	1,5
11.	Assorted jams	55	1,0
12.	Assorted fruit and berry jelly	35–40	0,7

The analysis of the products presented in Table 6.7 highlights that they combine dietary supplements with health benefits (BADS), responsible for binding toxic metals, with plant-based ingredients that contribute to improving organoleptic properties. Due to the low pectin content in products containing fresh plant ingredients or raw materials with a low dry matter content, achieving the necessary prophylactic dose requires the consumption of relatively large quantities, which may affect the overall dietary balance.

Increasing the pectin concentration is achieved by incorporating it into raw materials with high dry matter content, such as plums, apricots, and carrots, which also provide high biological and energetic value. The calculation of ingredients for the functional products was based on a recommended daily dose of 5 g of pectin with 10% moisture and a polyuronide content ≥70%, establishing a mass fraction of 20% pectin in the final product.

During the development of the production technology for functional products in the form of plant-based pectin bars, various technological schemes for candy production were analyzed. The process of obtaining functional products is based on this analysis, and the technological scheme for producing praline-type candies includes the following stages: preparation of the candy mass, shaping the bars by pressing into cords or strips, cooling the shaped cords, cutting them into individual bars, wrapping, and packaging in commercial packaging. However, experimental technological studies have shown that the process of producing functional food bars has certain particularities determined by the nature of the raw materials used and the characteristics of the final product.

The technological scheme developed by us includes the preparation of pectin, St. John’s wort flowers, and calendula flowers (Fig. 6.19), or, at the mixing stage, pre-prepared BADS can be used.

The technological scheme for producing SABA bars, presented in Fig. 6.19, includes the following process stages:

-reception and storage of raw materials;
-preparation of ingredients;
-mixing;
-concentration by boiling;
-preparation of the candy mass;
-shaping the candy mass;
-cooling;
-cutting into individual bars;
-wrapping;
-packaging in commercial packaging.

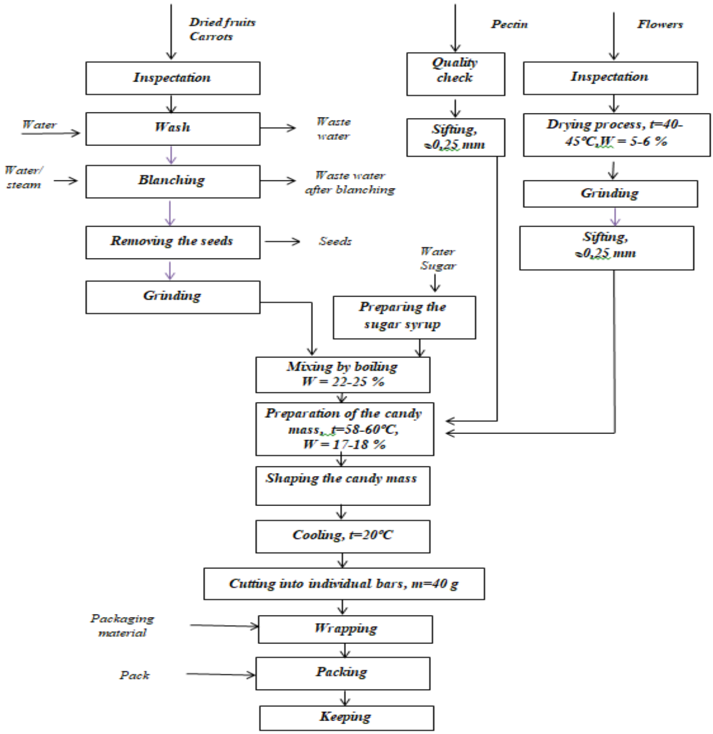


Fig. 6.19 The technological scheme of the production of bars with BADS

The collection, reception, storage of raw materials, and quality control were carried out in accordance with standardized requirements and the specific procedures for each technological stage. The calculation of product recipes was performed using the "from dry matter to natural" method (Lee et al., 2020), taking into account the established proportions of components, raw material loss norms (1.5% in the confectionery industry), and the dry matter content of the raw materials and the product. In this way, the recipes and consumption norms for raw materials and other inputs required for the production of functional food products were developed.

The analysis of the formulation composition and production costs for apricot, plum, and carrot-based bars determined the fraction of dry matter in the raw materials and included two variants for each type, differentiated by the presence of St. John's wort or calendula flowers, along with pectin, sugar, and water in variable proportions. The results showed significant differences in the efficiency of raw material utilization and the valorization of functional components. Formulations with flower extracts demonstrated satisfactory technological adaptability and competitive economic potential. Correlating the proportion of ingredients with the dry matter content allowed the identification of variants with superior efficiency in converting raw materials into the final product, facilitating the optimization of the composition according to nutritional, technological, and economic criteria.

6.5 Investigation of the shelf life of functional foods

Confectionery products with a high dry matter content belong to the category of products preserved by the anabiosis method, particularly through the reduction of water activity (Aw). Water activity is defined as the ratio between the vapor pressure of water above the product and the saturation vapor pressure of water at the same temperature. It is well known that the Aw level influences lipid oxidation processes, melanoidin formation, as well as enzymatic, fermentative, and microbiological activity during storage.

Critical Aw limits have been established for most microorganisms, above which their growth is inhibited. Thus, bacterial growth is favored at Aw = 0.90–0.99, while yeasts and molds can proliferate within an Aw range of 0.85–0.65. Depending on the water activity value, food products are classified into three categories: high-moisture products (Aw = 1.0–0.9), intermediate-moisture products (Aw = 0.9–0.6), and low-moisture products (Aw = 0.6–0.0).

With a moisture content of 18–20%, the functional products developed in this study fall into the category of intermediate-moisture products. The high concentration of sugars and pectin in their composition significantly contributes to retaining residual water after the manufacturing process, an effect further enhanced by the use of hermetic packaging.

Based on these considerations, it can be assumed that the analyzed functional products reduce or even eliminate conditions favorable for the growth of bacteria, yeasts, and molds. To validate this hypothesis, a series of experimental studies were conducted, the results of which are presented in Table 6.8.

Experimental series of apricot- and carrot-based bars were produced, each variant containing biologically active dietary supplements. The products were packaged in accordance with Sanitary Regulation No. 278 of 24.04.2013, using packaging that ensures the protection of quality and freshness during storage and transport.

Table 6.8 Physico-Chemical and Microbiological Indices of Bars During Storage

No.	Types of bars	Testing period	Mass fraction of moisture, %	Mass fraction of pectin, %	Degree of etherification of pectin	Microorganisms Aerobic and anaerobic mesophiles, CFU/g
1	**Apricot bar (variant 1)**	**Initially**	18,60	27,16	23,30	$2,4*10^3$
		4 months	18,61	27,20	23,00	$2,5*10^3$
		6 months	18,78	27,00	23,00	$2,5*10^3$
		8 months	18,750	27,10	22,91	$2,8*10^3$
2	**Apricot bar (variant 2)**	**Initially**	18,30	22,30	23,33	$2,7*10^3$
		4 months	18,42	22,35	23,40	$2,7*10^3$
		6 months	18,34	22,25	23,00	$2,8*10^3$
		8 months	18,40	22,31	29,84	$3,2*10^3$
3	**Carrot bar (variant 1)**	**Initially**	18,85	27,41	23,45	$1,3*10^3$
		4 months	18,80	27,40	23,00	$1,4*10^3$
		6 months	18,89	27,40	23,15	$1,5*10^3$
		8 months	18,91	26,95	23,00	$1,5*10^3$
4	**Carrot bar (variant 2)**	**Initially**	19,00	22,24	23,31	$2,1*10^3$
		4 months	19,00	22,30	23,18	$2,4*10^3$
		6 months	19,17	22,00	23,25	$3,3*10^3$
		8 months	19,23	22,00	23,30	$3,8*10^3$

The product quality was evaluated by monitoring the physico-chemical and microbiological parameters at intervals of 4, 6, and 8 months from the time of manufacture.

The analysis of the results presented in Table 6.8 highlighted that throughout the storage period, the bars maintained their sensory stability, without significant changes in color, odor, or texture. This indicates a stable shelf life of the product, due to the optimal dry matter content and the packaging used, which contributed to preventing oxidative processes and inhibiting the growth of spoilage microorganisms.

CONCLUSIONS

The research conducted within this thesis led to the formulation of the following conclusions:

1. The application of innovative research and development methods allowed for the diversification of extruded products with superior nutritional value, components of healthy diets. These products are characterized by a high content of dietary fibers (34.25–40.56%), proteins, minerals, and bioactive compounds, confirming the importance of sustainable utilization of secondary plant resources (Chapter 1, Iușan, 2023).

2. Physico-chemical analysis of local raw materials highlighted the high functional potential of cereals, legumes, and agro-food by-products. The addition of plant ingredients contributed to the improvement of the functional properties of extrudates, with relevant technological parameters being: expansion coefficient 3.95–4.60, water retention capacity 3.80–4.95 g/g, and oil retention capacity 0.85–1.05 g/g (Subchapter 4.1, Iușan, 2018).

3. Optimization of the drying process of grape pomace using combined technologies (convection + infrared radiation) and adjustment of parameters (temperature 75–85°C, air velocity 3 m/s, load 0.5–1.5 kg/m²) led to a 45% reduction in processing time, preservation of bioactive compounds, and increased energy efficiency. Mathematical modeling confirmed the validity of these solutions (Chapter 3, Iușan et al., 2020).

4. The developed recipes for functional food products, based on mathematical modeling and nutritional principles, demonstrated balanced combinations of ingredients. The study showed that recipes based on corn and grape pomace exhibited the best stability and accuracy of the predictive model, confirming the significant influence of polyphenols and marc acidity on the technological behavior of the mixtures (Chapter 4, Iușan, 2024).

5. Comprehensive evaluation of food product quality demonstrated full microbiological safety and superior texture and hydration parameters. The addition of citric acid (3%) reduced acrylamide formation by 15.9–21.1%, and the feasibility study confirmed the economic viability of the technologies, with efficiency ranging from 19.1–20.6% (Subchapters 4.1, 4.2, and 4.3, Iușan, 2020).

6. The study of the influence of technological parameters on the drying process revealed two distinct stages, with a transition point at 15–21% dry matter. Increasing the temperature reduced the drying time by up to 76% (in the case of grape pomace), while infrared radiation decreased the processing time by up to 15.5%, demonstrating the importance of thermal control and load management on dehydration kinetics (Subchapters 3.1 and 3.2; Iușan et al., 2020).

7. Advanced technologies for producing functional foods were designed and validated, based on scientific criteria for raw material selection and optimization of processing parameters. The obtained results confirm the efficiency and sustainability of these technological solutions, ensuring products with high biological value, increased stability, and sensory characteristics meeting modern consumer requirements (Subchapters 4.1 and 6.4, Iușan, 2022).

8. The determination of the nutritional and energy value of the products confirmed their significant contribution to fibers, proteins, and bioactive compounds. In addition, the internal radioactivity was reduced by 12.5%, and the elimination of radioactive metals was accelerated by a factor of 1.5 in clinically validated biologically active supplements. These findings confirm the positive impact of these products on human health (Subchapters 4.3 and 6.3, Iușan, 2023).

9. The feasibility and applicability of the proposed technologies were experimentally and industrially confirmed through implementation at "Policom-Prim" SRL, "BIOCOM" SRL, and "CONSULT LC" SRL. The development of normative-technical documentation demonstrated compliance with quality and food safety standards, and practical implementation confirmed the economic and industrial utility of the research (Subchapters 4.1 and 5.2, Iușan, 2024).

RECOMMENDATIONS

For the food industry in the Republic of Moldova, it is recommended to implement the developed extrusion technologies with optimal parameters: temperatures of 139–154°C and pressures of 25–30 MPa, for the valorization of food waste into products with increased dietary fiber content. The use of combined drying methods at optimal parameters of 75–85°C and an air velocity of 3 m/s ensures a reduction in processing time by up to 45% while preserving bioactive compounds.

In the field of research and development, it is recommended to expand investigations on optimizing the pectin-to-metal ratio to maximize the efficiency of toxic metal binding, deepen clinical studies to validate the long-term effects of SABA on health, and develop new compositions with local medicinal plants. Future research should also aim to investigate the synergies between different bioactive compounds to optimize the functional properties of the developed products.

For industrial-scale implementation, it is recommended to create pilot centers to demonstrate the viability of technologies at an industrial scale, with an emphasis on process standardization and quality control. Developing partnerships between research institutions and the food industry will facilitate rapid technology transfer and the implementation of innovations in commercial production.

In the context of public policy, it is recommended to develop a legislative framework to promote the valorization of food waste and establish national standards for functional foods and detoxifying supplements. Financial support for applied research programs and the implementation of educational programs promoting the consumption of nutritionally enhanced food products will contribute to improving the population's health status.

IMPACT AND DEVELOPMENT PROSPECTS

The obtained results contribute significantly to reducing food waste through the full valorization of by-products from the agro-food industry, estimating a reduction of up to 30% in the amount of waste generated. Improving the population's health through the development of functional food products with increased dietary fiber and bioactive compounds will have a positive impact on reducing metabolic and digestive disorders.

The economic sustainability of the food industry, through the diversification of the product portfolio, was confirmed by demonstrated profitability, ranging between 19.1–20.6% for extruded products, with estimated direct costs of 13,436–23,501.5 lei/ton (prices y. 2024). At the same time, the results indicate favorable conditions for the market launch of these products at a competitive price level. Environmental protection, ensured through the implementation of eco-friendly processing technologies, also contributes to strengthening the principles of sustainable development in the food sector.

The developed food technologies represent a forward-looking solution for the modern agro-food sector, providing concrete responses to contemporary challenges related to food safety, consumer health, and ecological responsibility. The implementation of these technologies will contribute to the development of a sustainable, competitive food industry oriented towards promoting consumer health and well-being, meeting the modern market's demand for healthy, sustainable, and safe food products.

The scientific results obtained can serve as a basis for future applied research, including technological transfer projects, bi- and multilateral international projects, as well as for securing doctoral research grants. Continued research will involve new analytical methods, including in situ digestibility studies of the developed products.

SELECTIVE BIBLIOGRAPHY

1. ABRAMOV, O. (2007) Issledovanie osnovnykh zakonomernostey protsessa ekstruzii pri proizvodstve kombinirovannykh produktov pitaniya. *Khranenie i pererabotka sel'khozsyr'ya*, 6, pp. 69–72. (in Russian)

2. ACEVEDO, N., SCHEBOR, C. et al. (2006) Water–solids interactions, matrix structural properties and the rate of non-enzymatic browning. *Journal of Food Engineering*, 77, pp.1108–1115. https://doi.org/10.1016/j.jfoodeng.2005.08.045

3. ACKMAN, R.G. (2007) Fatty acids in fish and shellfish. C.K. Chow, ed. *Fatty Acids in Foods and Their Health Implications*. London, UK: CRC Press, pp. 155–185 DOI:10.1201/9781420006902.ch8

4. AIDIGIÉ, C., ZONSZAIN, F. (2007) *Biochimie structurale*. Doin, Rueil-Malmaison, 1 vol., XI–p.266

5. ALAM, M.S., PATHANIA, S. et al. (2016) Optimization of the extrusion process for development of high fibre soybean-rice ready-to-eat snacks using carrot pomace and cauliflower trimmings. *LWT – Food Science and Technology,* 74, p.135-144, https://doi.org/10.1016/j.lwt.2016.07.031

6. ALTAN, A. and MASKAN, M. (2011) Development of extruded foods by utilizing food industry by-products. In: Advances in food extrusion technology, p.121-168. DOI:10.1201/b11286-7

7. ARYAL, S. (2023) Proteins: Properties, Structure, Types, Functions. *Microbe Notes*. Available at: https://microbenotes.com/amino-acids-proteins/ [Accessed 15 August 2025]

8. BHATKAR, N.S., SHIRKOLE, S.S., MUJUMDAR, A.S. et al. (2021) Drying of tomatoes and tomato processing waste: a critical review of the quality aspects. *Drying Technology,* 39 (11), pp. 1720-1744, https://doi.org/10.1080/07373937.2021.1910832

9. BLAUROCK-BUSCH, E. (2020) Pectin an Alternative to Synthetic Chelators. *Townsend Letter,* p.1–5. https://www.townsendletter.com/article/pectin-an-alternative-to-synthetic-chelators

10. BRIGHINA, S., PULVIRENTI, L., SIRACUSA, L. et al. (2024) Small-sized tomato pomace: source of bioactive compounds and ingredient for sustainable production of functional bread. *Foods*, 13(21):3492. doi: 10.3390/foods13213492

11. BYKOVA, T.O., MAKAROVA, N.V., SHEVCHENKO, A.F. (2015) The impact of drying technology on chemical composition and antioxidant properties of fruit pomace. *Pishchevaya Promyshlennost',* 12, p.68–70. (in Russian), https://cyberleninka.ru/article/n/vliyanie-tehnologii-sushki-na-himicheskiy-sostav-i-antioksidantnye-svoystva-fruktovyh-vyzhimok

12. CESKO, T., DICUSAR, G., GHENDOV-MOȘANU, A. (2022) Kinetics of the drying process of apple pomace by convective method. In: *Conferință Științifică Internațională „Perspectivele și Problemele Integrării în Spațiul European al Cercetării și Educației"*, USC, Cahul, pp.345–346, https://ibn.idsi.md/sites/default/files/imag_file/Volumul_IX-Part_1_2022.pdf

13. CEȘKO, T., DICUSAR, G., STURZA, R. et al. (2023) The influence of the temperature of the convective heat agent on the kinetics of the drying process and the content of bioactive compounds in apple pomace. *Journal of Engineering Science,* 30(3), p.134–144, https://doi.org/10.52326/jes.utm.2023.30(3).09

14. CHERNYKH, V.A. (2012) Opredelenie strukturno-mekhanicheskikh svoystv ekstrudatov. *Khranenie i pererabotka sel'khozsyr'ya,* 12, p.22–24. (in Russian)

15. Codex Alimentarius (1979) *Standard for Foods for Special Dietary Use for Persons Intolerant to Gluten (CXS 118-1979, Revizuire 2015),* p.39, https://www.fao.org/fao-who-codexalimentarius/sh-

proxy/ru/?lnk=1&url=https%253A%252F%252Fworkspace.fao.org%252Fsites%252Fcodex%252FStandards%252FCXS%2B118-1979%252FCXS_118e_2015.pdf&utm

16. CONTE, A., PANZA, O., DEL NOBILE, M.A. (2024) Modeling the dehydration kinetic of grape pomace. *LWT – Food Science and Technology*, 198:116021, https://doi.org/10.1016/j.lwt.2024.116021

17. CSPI (2016) *Artificial Trans Fat: A Timeline*. Available at: https://cspinet.org/resource/artificial-trans-fat-timeline [Accessed 10 August 2025]

18. DAHL, W., STEWART, M. (2015) Position of the Academy of Nutrition and Dietetics: Health Implications of Dietary Fiber. *Journal of The Academy of Nutrition and Dietetics*, 115(11), pp. 1861–1870, https://www.jandonline.org/article/S2212-2672(15)01386-6/abstract

19. DELFIYA, D.S.A., et al. (2022) Drying kinetics of food materials in infrared radiation drying: A review. *Journal of Food Process Engineering*, 45(6), e13810, https://doi.org/10.1111/jfpe.13810

20. EVERT, A.B., BOLEN, S., MURRAY, S. (2019) Nutrition Therapy for Adults With Diabetes or Prediabetes: A Consensus Report. *Diabetes Care*, 42(5), pp.731–754, https://doi.org/10.2337/dci19-0014

21. FAO (2008) *Food and Nutrition Paper 91: Fats and fatty acids in human nutrition. Report of an expert consultation.* Geneva, https://www.fao.org/fileadmin/user_upload/nutrition/docs/requirements/fatsandfattacidsreport.pdf?utm

22. FARDET, A., ROCK, E. (2014) Toward a new philosophy of preventive nutrition: from a reductionist to a holistic paradigm to improve nutritional recommendations. *Advances in Nutrition*, 5 (4), pp.430–446, https://doi.org/10.3945/an.114.006122

23. FIRA-MLĂDINESCU, C. (2019) *Macronutrienții și micronutrienții în Ghid de bune practice*. In: Alimentație rațională, siguranța alimentelor și schimbarea comportamentului alimentar. Chișinău: Print-Caro, pp.25–28, https://repository.usmf.md/handle/20.500.12710/6742

24. FONTANA, A.R., ANTONIOLLI, A., BOTTINI, R. (2013) Grape pomace as a sustainable source of bioactive compounds: extraction, characterization, and biotechnological applications of phenolics. *Journal of Agricultural and Food Chemistry*, 61(38), DOI:10.1021/jf402586f

25. GOŁĘBIOWSKI, A., et al. (2020) Molecular parameters of low methoxylated pectin affected by gelation with copper and cadmium cations, *Bioactive Carbohydrates and Dietary Fibre*, 21:100211, DOI:10.1016/j.bcdf.2020.100211

26. GONCHARUK, V., et al. (2023) Heavy metal, their phytotoxicity, and the role of phenolic antioxidants in plant stress responses with focus on cadmium: Review. *Molecules*, 28(9):3921 doi: 10.3390/molecules28093921

27. HERAS-RAMÍREZ, M., QUINTERO-RAMOS, A., CAMACHO, A. et al. (2011) Effect of Blanching and Drying Temperature on Polyphenolic Compound Stability and Antioxidant Capacity of Apple Pomace. *Food and Bioprocess Technology*, 5(6), pp. 1-10, DOI:10.1007/s11947-011-0583-x

28. HUANG, D., YANG, P., TANG, X. et al. (2021) Application of infrared radiation in the drying of food products. *Trends in Food Science and Technology*, 110, p.765–777, https://doi.org/10.1016/j.tifs.2021.02.039

29. **IUŞAN, L.,** TERENTIEVA, G., CARAGIA, V. et al. (2014) Prophylactic assortiment diversification of food for diabetics. In: *Proceedings of International Conference Modern Technologies in the Food Industry*, Chișinău: Technical University of Moldova, pp. 216–219, https://repository.utm.md/handle/5014/6835?show=full

30. **IUSHAN, L.** (2022) Improving the recipes of extruded soryz mixes using wheat germ. *Sciences of Europe*, 94, p. 86, doi:10.5281/zenodo.6616429

31. JAKÓBIK-KOLON, A. et al. (2014) Preparation of pectin-based biosorbents for cadmium and lead ions removal. *Separation Science and technology*, 49(11). DOI:10.1080/01496395.2014.906469

32. KAUR, R.**,** KUMAR, M.**,** GUPTA, O.P. et al. (2018) Drying Characteristics of Fenugreek and Its Computer Simulation for Automatic Operation. *International Journal of Current Microbiology and Applied Sciences*, 7(03), p.3275–3291, DOI:10.20546/ijcmas.2018.703.378

33. KAUSER, S., MURTAZA, M.A., HUSSAIN, A., et al. (2023) Apple pomace, a bioresource of functional and nutritional components with potential of utilization in different food formulations: A review. *Food Chemistry Advances,* 4(10):100598, DOI:10.1016/j.focha.2023.100598

34. KHOTIMCHENKO, I. et al. (2007) Low esterified pectin accelerates removal of lead ions in rats. *Nutrition Research*, 27(10), p.633-639, DOI:10.1016/j.nutres.2007.06.005

35. KHOTIMCHENKO, M., et al. (2017) Lead-binding capacity of calcium pectates with different molecular weight. *International Journal of Biological Macromolecules*, 97, p.526-535. DOI: 10.1016/j.ijbiomac.2017.01.065

36. LERSANANSIT, N., PUNGJUNUN, K., CHAILAPAKUL, O. & PRAPHAIRAKSIT, N., (2024) Development of pectin-based gel electrolyte for wireless electrochemical determination of cadmium and lead using smartphone. *Talanta*, 263, p.126211. doi:10.1016/j.talanta.2024.126211

37. LI, D. et al. (2021) Characterizing and alleviating the browning of choerospondias axillaris fruit cake during drying. *Food Control*, 132(9):108522, DOI:10.1016/j.foodcont.2021.108522

38. LI, R., WANG, C., WANG, Y. et al. (2023) Extrusion modification of wheat bran and its effects on structural and rheological properties of wheat flour dough. *Foods*, 12(9):1813 https://doi.org/10.3390/foods12091813

39. LI, Y.O. and KOMAREK, A.R. (2017) Dietary fibre basics: Health, nutrition, analysis, and applications. *Food Quality and Safety*, 1(1), p.47–59, https://doi.org/10.1093/fqsafe/fyx007

40. LIU, X., et al. (2021) Exploring interactions between pectins and procyanidins: Structure-function relationships. *Food Hidrocolloids*, 113(29):106498, DOI:10.1016/j.foodhyd.2020.106498

41. MI MOON, K., KWON, E.-B., LEE, B. et al (2020) Recent trends in controlling the enzymatic browning of fruit and vegetable products. *Molecules*, 25(12), 2754. https://doi.org/10.3390/molecules25122754

42. MIHU, I. (2012) *Boala celiacă la copii. Protocol clinic nutrițional.* Chisinau: Ministerul Sănătății al RM, p.29 https://repository.usmf.md/bitstream/20.500.12710/10406/1/Boala_celiaca_la_copil_Protocol_clinic_national_PCN_167.pdf

43. MINZANOVA, S., et al. (2015) Reversible complexation of heavy metals by pectin and its effect on electrochemical properties. *Carbohydrate Polymers*, 115, p.123–130 DOI:10.1016/j.carbpol.2015.07.034

44. MIRONEASA, S., COŢOVANU, I., MIRONEASA, C. (2023) A Review of the Changes Produced by Extrusion Cooking on the Bioactive Compounds from Vegetal Sources, *Antioxidants*, 12(7), 1453, https://doi.org/10.3390/antiox12071453

45. MIRONEASA, S., UNGUREANU-IUGA, M., URSACHI, V.-F. et al. (2024) Seedless grape pomace to increase fiber content in extruded corn snacks. *Ukrainian Food Journal*, 13(4), p.657-674, DOI:10.24263/2304-974X-2024-13-4-3

46. NICOLAEVA, D., PODOGOVA, M., SLUHINSCHI, S. (2004) Perspektivy tekhnologii proizvodstva productii na osnove ekstrudirovannykh komponentov. *Khranenie i pererabotka zerna*, 9(63), p.51–52 (in Russian)

47. OTLES, S. and OZGOZ, S. (2014) Health effects of dietary fiber. *Acta Scientiarum Polnorum Technologia Alimentaria*, 13(2), p.191–202. https://pubmed.ncbi.nlm.nih.gov/24876314/

48. PAVLINCIUC, M., ŞLEAGUN, G., **IUŞAN, L.,** et al. (2020) Compararea diferitor regimuri de uscare a perelor deshidratate prin osmoză, utilizând convecţia şi radiaţia infraroşie. In: *Realizări științifice în horticultură, oenologie și tehnologii alimentare. IȘPHTA – 110 ani de activitate*, Chișinău, pp.440–445, https://ibn.idsi.md/vizualizare_articol/190430

49. *Raport al Comisiei către Consiliul și Parlamentul European privind dezvoltarea proteinelor vegetale în Uniunea Europeană*. (2018) Bruxelles. Available at: https://op.europa.eu/mt/publication-detail/-/publication/360e27f0-ee4d-11e8-b690-01aa75ed71a1/language-ro/format-PDF [Accessed 28 June 2025]

50. ROCCHETTI, G., et al. (2022) Functional implications of bound phenolic compounds and phenolics-food interaction: A review. *Comprehensive Reviews in Food Science and Food Safety*, 21 (2), p.811-842, https://doi.org/10.1111/1541-4337.12921

51. SATTERFIELD, M. and BRODBELT, J. (2000) Enhanced detection of flavonoid by metal complexation and electrospray ionization mass spectrometry. *Analytical Chemistry*, 72(24), p.5898–5906, doi: 10.1021/ac0007985.

52. SINAKI, N.Y. (2024) Effects of dietary fibre source and content and extrusion conditions on the physicochemical composition and physical quality of fibre-enriched lentil snacks. *International Journal of Food Science and Technology*, 59(4), pp. 2236-2247 DOI:10.1111/ijfs.16943

53. SLEAGUN, G. and **IUSHAN, L.** (2023) Evaluation of fruit raw materials for the production of structured snacks. *Scientific discussion*, Vol.1, 78, pp.15–19, DOI: 10.5281/zenodo.8123206

54. ȘLEAGUN, G., **IUȘAN, L.**, ZÎREANOVA, E. (2025) Revizuirea tendințelor în dezvoltarea snackurilor din fructe structurate cu proprietăți funcționale. *Akademos*, 1(76), pp.22–30, DOI:10.52673/18570461.25.1-76.03

55. TUTEL"YAN, V. (2001) Biologicheski aktivnye dobavki k pishche v profilakticheskom i lechebnom pitanii. *Pervaya kraevaya, ezhekvartal'nyy meditsinskiy zhurnal*, 11, p.31–35 (in Russian)

56. TUTEL"YAN, V.A., VYALKOV, A.I., RAZUMOV, A.N. et al. (2010) *Nauchnye osnovy zdorovogo pitaniya*. Moscow: Izdatel'skiy dom „Panorama”, p.816 (in Russian)

57. USHKALOVA, E.V. (2001) Vzaimodeystvie lekarstvennykh sredstv s pishchevymi produktami. *Novaya apteka*, 12, p.17–20 (in Russian)

58. YAGCI, S. et al. (2022) Impact of tomato pomace powder added to extruded snacks on the in vitro gastrointestinal behaviour and stability of bioactive compounds. *Food Chemistry*, 368, p.130847, doi: 10.1016/j.foodchem.2021.130847

LIST OF SCIENTIFIC WORKS ON THE THESIS TOPIC

published during the 2005–2025 on the topic of the thesis by Larisa IUȘAN, Doctor of Technical Sciences, Head of the Food Technology and Microbiology Department, National Institute for Applied Research in Agriculture and Veterinary Medicine, Chișinău.

1. Specialized Books

1.1 Specialized Books – Single Author

1. IUȘAN, L. Tehnologii inovative în fabricarea produselor alimentației sănătoase. Monografia. Tipografia "PrintCaro", Chișinău. 2023. p. 227. ISBN 978-9975-165-45-7

2. Articles in scientific journals

2.1. in journals from the Web of Science and SCOPUS databases

1. YUSHAN, L. D. Study of polyphenols content in extruded mix. In: *Scientific Study & Research - Chemistry & Chemical Engineering, Biotechnology, Food Industry*, "Vasile Alecsandri" University of Bacău, Romania, Vol. XXV (2), pp. 223-229, 2024. ISSN 1582-540X. **IF: 0.7.** https://doi.org/10.29081/ChIBA.2024.585

2.2 in recognized foreign journals

1. TERENTYEVA, G.N., KARAZHIYA, V.F., **YUSHAN, L.D.,** SARANDI, T.A., SUVOROVA, G. Grape leaves and methods of conservation. In: *Vegetable crops of Russia*. 2014; (1), pp. 64-67. (In Russ.) https://doi.org/10.18619/2072-9146-2014-1-64-67
ISSN 2072-9146 (Print); ISSN 2618-7132 (Online) **(indexată în DOAJ, EBSCO)**

2. IUSHAN, L., KARELINA, M., ZYRYANOVA, E., TERENTIEVA, G., VICHEROVA, L. Application of CO2 extract from the mixture of spices with high content of biologically active components and natural flavors in the preparation of certain types of food products. In: *The scientific heritage*. Budapest, Hungary, 2023, No 122 (122), ISSN 9215 — 0365, pp. 12-16; https://www.scientific-heritage.com/wp-content/uploads/2023/10/The-scientific-heritage-No-122-122-2023.pdf (**indexată în DOAJ**)

3. YUSHAN, L., KARELINA, M., ZYRYANOVA, E., VICHEROVA, L. (2025) Introduction CO2 spice extracts into food. *Journal of Agroalimentary Processes and Technologies*, 31(4), pp. 423-429. ISSN: 2069-0053 (print), Agroprint ISSN (online): 2068-9551
https://journal-of-agroalimentary.ro/admin/articole/52492L3-31.4-YUSHAN-DOI-4.3--pp-423-429.pdf (**indexată EBSCO**)

4. IUSHAN, L., TARAN, N., KARELINA, M., TERENTIEVA, G., ZYRYANOVA, E. The use of fat-soluble CO_2-extracts from spices with high content of biologically active substances in the fabrication of dressings. In: *Danish Scientific Journal*, 2024,

81. ISSN 3375-2389, Vol.1 https://www.danish-journal.com/wp-content/uploads/2024/03/DSJ_81.pdf (Cosmos Impact Factor - 5.195)

5. YUSHAN, L., PARSHACOVA, L., POPEL, S. Justification of the nutritional and energy value of low-calorie mayonnaise based on vegetable oils with a balanced content of polyunsaturated fatty acids. In: *ISRG Journal of Multidisciplinary Studies (ISRGJMS)*, 2024, X (october), Volume – II Issue. ISSN: 2584-0452 (Online) - DOI: 10.5281/zenodo.14000393 (SJIF – 3.767)

6. SLEAGUN, G., **IUSHAN, L**. Evaluation of fruit raw materials for the production of structured snacks. In: *Scientific discussion*, Praha, Czech Republic, 2023, VOL 1, No 78, pp. 15-19 ISSN 3041-4245. https://scientific-discussion.com/wp-content/uploads/2023/07/Scientific-discussion-No-78-2023.pdf

7. IUSHAN, L. Improving the recipes of extruded soryz mixes using wheat germ. In: *Sciences of Europe*. Praha, Czech Republic, 2022, No 94, ISSN 3162-2364, p. 86. DOI: 10.5281/zenodo.6616429 (SJIF – 5.974)

2.3 in journals from the National Register of specialized journals, indicating the category

1. ȘLEAGUN, G., **IUȘAN, L**., ZÎREANOVA, E. Revizuirea tendințelor în dezvoltarea snackurilor din fructe structurate cu proprietăți funcționale. In: *Akademos*, nr.1 (76), 2025. Chișinău. pp. 37-45, ISSN 1857-0461 **(Cat. B)** https://doi.org/10.52673/18570461

2. POPEL, S., **IUȘAN, L.,** PARSHAKOVA, L., ZÎREANOVA, E., DRAGANOVA, E. Îndulcitori alimentari: tipologie, reglementări și impactul asupra sănătății consumatorului. In: *Pomicultura, Viticultura şi Vinificaţia,* nr. 1 [93], 2025. Chișinau. pp. 45-51. ISSN 1857-3142 **(Cat. C)**. CZU: 664.8. https://doi.org/10.53082/1857-3142.25.93.08

3. POPEL, S., **YUSHAN, L.,** DRAGANOVA, E., PARSHAKOVA, L., ZYRYANOVA, E., PUZHAILO, E. The development of technology for combined food products. In: *Pomicultura, Viticultura şi Vinificaţia,* nr. 2 [92], 2024. Chișinau. pp. 63-70. ISSN 1857-3142 **(Cat. C)**. CZU: 664.8 https://doi.org/10.53082/1857-3142.24.92.11

4. IUȘAN, L. Utilizarea rațională a CO_2-șrotului din semințe de struguri pentru obținerea produselor extrudate cu valoare biologică sporită. In: *Pomicultura, Viticultura şi Vinificaţia*, nr.1 [91], 2024. Chișinau. pp. 52-58. ISSN 1857-3142. **(Cat. C).** CZU: 664.542.69:621.867 https://doi.org/10.53082/1857-3142.24.91.11

5. ȘLEAGUN, G., **IUȘAN, L.,** FIODOROV, S., ZÎREANOVA, E. Aspecte teoretice ale tehnologiei de uscare a dovleacului. In: *Pomicultura, Viticultura şi Vinificaţia*, nr.1 [91], 2024. Chișinau. pp. 45-51. ISSN 1857-3142 **(Cat. C).** CZU: 664.844:635.62 https://doi.org/10.53082/1857-3142.24.91.10

6. ŞLEAGUN, G., **IUȘAN, L.,** CUPCEA, T., GORDEEVA, V. Cercetări privind stabilirea unor legături dintre compoziția și procesul de structurare a fructelor-snack-uri. In: *Pomicultura, Viticultura şi Vinificaţia*, nr. 2 [90], 2023. Chişinau. pp. 45-51. ISSN 1857-3142. **(Cat. C)**. CZU: 664.8/9 https://doi.org/10.53082/1857-3142.23.90.09
7. POPEL, S., **IUȘAN, L.,** DRAGANOVA, E., PARȘACOVA, E., PÎRGARI, E., ZÎREANOVA, E., PUJAILO, E. Фруктовые напитки повышенной пищевой ценности. In: *Pomicultura, Viticultura şi Vinificaţia*, nr. 1 [89], 2023. Chişinau. pp. 62-67. ISSN 1857-3142. **(Cat. C).** CZU 664.8 https://doi.org/10.53082/1857-3142.23.89.09
8. ŞLEAGUN, G., **IUȘAN, L.,** CUPCEA, T. Разработка и применение балльной шкалы для органолептической оценки качества фруктовых снеков. In: *Pomicultura, Viticultura şi Vinificaţia,* nr.1 [87], 2022. Chişinau. pp. 48-54. ISSN 1857-3142. **(Cat. C)**. CZU: 664.8.047 https://doi.org/10.53082/1857-3142.22.87.06
9. POPEL, S., **IUȘAN, L.,** DRAGANOVA, E., PÎRGARI, E., PARȘACOVA, L., ZÎREANOVA, E., PUJAILO, E. Produse îmbogățite cu fibre alimentare pentru alimentație sănătoasă. In: *Pomicultura, Viticultura şi Vinificaţia,* nr.2 [88], 2022. Chişinau. pp. 55-66. ISSN 1857-3142. **(Cat. C)**. CZU: 664.8 https://doi.org/10.53082/1857-3142.22.88.09
10. MIGALATIEV, O., **IUŞAN L.,** CARELINA, M. Valorificarea șrotului din condimente obținut prin tehnologia de CO_2-extracție. In: *Pomicultura, Viticultura și Vinificația*, nr. 2 [86], 2021. Chişinau. pp. 11-17. ISSN 1857-3142. **(Cat. C).** CZU: 664.34:664.5:664.69 https://doi.org/10.53082/1857-3142.21.86.03
11. IUŞAN, L., TERENTIEVA, G., CARAGIA, V., MIGALATIEV, O., CARELINA, M. Elaborarea amestecurilor complexe extrudate din materie primă autohtonă cu conţinut sporit de amidon. In: *Pomicultura, Viticultura şi Vinificaţia*, nr. 4 [76], 2018. Chişinau. pp. 35-37. ISSN 1857-3142. **(Cat. C**). CZU: 664.3:635.621. https://ibn.idsi.md/sites/default/files/imag_file/35-37_11.pdf
12. IUȘAN, L., TERENTIEVA, G., CARAGIA, V. Conserve pe bază de fructe şi legume cu conținut redus de zahăr pentru alimentația copiilor sugari și de vărsră mică. In: *Pomicultura, Viticultura şi Vinificaţia*, nr. 2 [68], 2017. Chişinau. pp. 29-31. ISSN 1857-3142. **(Cat. C).** CZU: 664.3:635.621 https://ibn.idsi.md/sites/default/files/imag_file/29-31_11.pdf
13. IUŞAN, L., TERENTIEVA, G., CARAGIA, V., GORGAN, L. Elaborarea unui nou sortiment de produse alimentare din dovleac. In : *Pomicultura, Viticultura şi Vinificaţia*, nr.5-6 [59-60], 2015. Chişinau. pp. 62-64. ISSN 1857-3142. **(Cat. C).** CZU: 664.3:635.621 https://ibn.idsi.md/sites/default/files/imag_file/64-66_11.pdf
3. Articles in the Proceedings of Conferences and Other Scientific Events
3.1 in the proceedings of scientific events indexed in the Web of Science and SCOPUS databases

1. POPEL, S., EPIFANOV*, P., **YUSHAN, L.** Factors affecting the quality of apple juice. In: BIO Web of Conferences: Biologization of the Intensification Processes in Horticulture and Viticulture, Ed. 1, 21-23 septembrie 2021, Krasnodar. Les Ulis: EDP Sciences, 2021, Vol. 34, pp. 1-6. ISSN e: 2117-4458. https://doi.org/10.1051/bioconf/20213406011

3.2 in the proceedings of scientific events included in other databases accepted by ANACEC

1. YUSHAN, L., TARAN, N., TERENTIEVA, G., ZYRYANOVA, E. The Development Of The Encapsulation Of Bioactive Compounds From Flax And Milk Thistle Seeds - *Proceedings of the International Conference Modern Technologies in the Food Industry-2024.* MTFI-2024, 17-18 October 2024, Chisinau: Tehnica-UTM, 2024. – p. 125. ISBN 978-9975-64-472-3 (PDF). https://conferinte.stiu.md/sites/default/files/evenimente/Materialele-Conferintei-MTFI-2024_1.pdf

2. MIGALATIEV, O., **IUŞAN, L.,** CARELINA, M. Study of noodles manufacturing with addition of CO_2-meal from the spice blend. Scientific Collection «InterConf+», Proceedings of the 5th International Scientific and Practical Conference: *Current issues and prospects for the development of scientific research*, No. 12(105), April 19-20, 2022, Orléans, France: Epi, 2022, ISBN 978-2-7045-4521-6, pp. 412–418; https://doi.org/10.51582/interconf.19-20.04.2022.039

3. MIGALATIEV, O., **IUŞAN, L.,** CARELINA, M., VÎCEROVA L. Chicken liver pate with liposoluble flavoring extracts. *Scientific Collection "InterConf", 2022, 51, pp. 381-387* https://archive.interconf.center/index.php/conference-proceeding/article/view/950

4. MIGALATIEV, O., CARELINA, M., **IUŞAN, L.** Creation of vegetable ingredients from spice blends. *Scientific Collection «InterConf», 2021, 69, pp. 195-203* https://ojs.ukrlogos.in.ua/index.php/interconf/article/view/14048.

5. ПАРШАКОВА, Л. П., ПОПЕЛЬ, С. С., **ЮШАН,, Л. Д.,** ДРАГАНОВА, Е. И., ПЫРГАРЬ, Е. П., ЗЫРЯНОВА, Е. В., ВЫЧЕРОВА, Л. С., ПУЖАЙЛО, Е. Н. Увеличение сроков годности низкокалорийных майонезов при помощи антиоксидантов, *Наука, питание и здоровье: материалы III Международного конгресса,* сборник научных трудов, Национальная академия наук Беларуси, Научно-практический центр Национальной академии наук Беларуси по продовольствию, Минск, 24-25 июня 2021 г., ISBN 978-985-08-2745-6, с. 210-215. https://old.belproduct.com/assets/files/chast-1.pdf

6. ЮШАН, Л. Д., ТАРАН Н. Г., ТЕРЕНТЬЕВА Г. Н., МИГАЛАТЬЕВ О. В. Особенности использования местного зернового сырья для производства продуктов здорового питания, *Наука, питание и здоровье* : *материалы III Международного конгресса*, сборник научных трудов, Национальная академия наук Беларуси, Научно-практический центр Национальной академии наук

Беларуси по продовольствию, Минск, 24-25 июня 2021 г., ISBN 978-985-08-2745-6, с. 335-339. https://old.belproduct.com/assets/files/chast-1.pdf

7. **IUŞAN, L.,** TERENTIEVA, G., CARAGIA, V., MIGALATIEV, O., CARELINA, M., GORDEEVA, V. Développement de la technologie de fabrication de bouillie instantanée aux personnes présentant une intolérance au gluten. *Proceedings of International Conference Modern Technologies in the Food Industry,* Technical University of Moldova, Chişinău, 18-20 October 2018, pp. 291-296, ISBN 978-9975-87-428-1. https://ibn.idsi.md/vizualizare_articol/80379

8. ЛИНДА Л. П, КНЯЗЕВА С. Д., КАРАЖИЯ В.Ф., САРАНДИ Т.А., **ЮШАН Л.Д.**, ОДОБЕСКУ Л.В., ГОРДЕЕВА В.Н. Продукты здорового питания из плодов нетрадиционной культуры ziziphus jujuba mill. *Перспективные технологии хранения и переработки сельскохозяйственной продукции*, Северо-кавказский федеральные научный центр садоводства и виноградарства, Краснодар 3-7 сентября, 2018, Том 17, с.163-166

DOI 10.30679/2587-9847-2018-17-163-166

https://kubansad.ru/media/uploads/files/nauchnye_trudy_skzniisiv/tom_17/27.pdf

9. IUŞAN, L.; TERENTIEVA, G.; CARAGIA, V.; GORDEEVA, V. Prophylactic assortiment diversification of food for diabetics. *Proceedings of International Conference Modern Technologies in the Food Industry*, Technical University of Moldova, Chişinău, 16-18 October, 2014, pp. 216-219, ISBN 978-9975-80-840-8.

10. TERENTIEVA, G., **YUSHAN, L.,** CARAGIA, V. Prospects for complex food processing of pumpkin. In: *Biologically Active Substances and Materials: Fundamental and Applied Problems,* May 27 – June 1, 2013, Novy Svet, Crimea, Ukraine, p. 348. ISBN 978-966-96879-9-9. https://ibn.idsi.md/sites/default/files/imag_file/348-348_4.pdf

3.3 in the proceedings of scientific events included in the Register of Materials Published on the Basis of Scientific Events Organized in the Republic of Moldova

1. ȘLEAGUN, G., **IUȘAN, L.,** PAVLINCIUC, M.,COJUCARI, L. Principiile moderne ale alimentației sănătoase în baza dezvoltării unui sortiment nou de produse alimentare. Conferinţa naţională cu participare internaţională „*Știința în nordul Republicii Moldova: probleme,realizări, perspective*” (ediția a cincea),. BĂLŢI, 25-26 iunie 2021, ISBN 978-9975-62-432-9, pp. 180-185

https://ibn.idsi.md/sites/default/files/imag_file/Sectia_Nord_a_Academiei_Stiinte_Moldovei_editia_5_2021.pdf

2. LINDA L., ODOBESCU L., **IUȘAN L.,** GORDEEVA V., PARŞACOVA L. Sosuri pentru o alimentaţie sănătoasă, cu valoare nutritivă şi biologică sporită, din materii prime cultivate în Republica Moldova. In: *Realizări științifice în horticultură, oenologie și tehnologii alimentare.* IȘPHTA – 110 ani de activitate. Chișinău 2020, pp. 378-383; CZU 664.3:635.621

https://ibn.idsi.md/sites/default/files/imag_file/Realizari_stiintifice_in_horticultura_oenologie_si_tehnologii_alimentare_2020.pdf

3. IUȘAN, L., TERENTIEVA, G., COJUCARI, L. Aspecte științifice și practice privind utilizarea extrudatelor culturilor cerealiere în tehnologia obținerii produselor alimentare profilactic-curative. In: *Realizări științifice în horticultură, oenologie și tehnologii alimentare*. IȘPHTA – 110 ani de activitate. Chișinău 2020, pp. 355-360; CZU 664:542.69:621.867.4
https://ibn.idsi.md/sites/default/files/imag_file/Realizari_stiintifice_in_horticultura_oenologie_si_tehnologii_alimentare_2020.pdf

4. MIGALATIEV, O., CARELINA, M., **IUȘAN, L.,** CARAGIA, V. Utilizarea CO_2-şrotului din deşeuri de tomate la fabricarea pâinii din făină de grâu de calitate superioară. In: *Realizări științifice în horticultură, oenologie și tehnologii alimentare.* IȘPHTA – 110 ani de activitate. Chișinău 2020, pp. 361-365; CZU:635.64; 664.34; 664.849; 664.665
https://ibn.idsi.md/sites/default/files/imag_file/Realizari_stiintifice_in_horticultura_oenologie_si_tehnologii_alimentare_2020.pdf

5. PAVLINCIUC, M., ŞLEAGUN, G., **IUŞAN, L.,** POPA, M., CUPCEA, T. Compararea diferitor regimuri de uscare a perelor deshidratate prin osmoză, utilizând convecţia şi radiaţia infraroşie. In: *Realizări științifice în horticultură, oenologie și tehnologii alimentare*. IȘPHTA – 110 ani de activitate. Chișinău 2020, pp. 440-445. CZU 664.8.035.5, 664.854:634.13
https://ibn.idsi.md/sites/default/files/imag_file/Realizari_stiintifice_in_horticultura_oenologie_si_tehnologii_alimentare_2020.pdf

6. IUŞAN, L., TERENTIEVA, G., CARAGIA, V., GORDEEVA, V. Conserve din fructe şi legume cu valoare biologică sporită pentru alimentaţia copiilor. În: *Agricultura durabilă în Republica Moldova: provocări, actuale și perspective*. Culegere de articole ştiinţifice. Bălţi:Indigou Color, 2017, pp. 94-96. ISBN 978- 9975-3156-2-3.
http://riora.usarb.md:4000/items/a48111ca-577f-46d6-b067-61e597895636

7. IUȘAN, L., VAVIL C. Getting eatable food from pumpkin district in Republic of Moldova. Simpozionul ştiinţific „Horticultură - ştiinţă, calitate, diversitate şi armonie", 29-31 mai, 2008, Iaşi, Ed. "Ion Ionescu de la Brad", Romania, p.74.

8. IUȘAN, L. Cercetarea şi elaborarea aditivului alimentar din dovleac raionat în Republica Moldova, Salonul Regional al Cercetării, EXPOTEHNICA, Bacău, 15-18 noiembrie 2007, p.16.

4. Patents and Other Intellectual Property Objects (IPO)

4.2 issued by the State Agency on Intellectual Property

1. ŞLEAGUN, G.; **IUȘAN, L.;** CUPCEA, T. Procedeu de obţinere a snack-urilor structurate de fructe. Brevet acordat MD 1660 din 2022.02.25.

2. IUŞAN, L., TERENTIEVA, G., MIGALATIEV, O. Procedeu de fabricare a produsului alimentar extrudat de cereale. Brevet acordat MD 4826 din 2021.06.29

3. IUŞAN, L., TERENTIEVA, G., COJUCARI, L., GORDEEVA, V. Sos de fructe şi legume. Brevet acordat MD 4857 din 2021.05.11

4. DICHINA, A., TERENTIEVA, G., CARAGIA, V., **IUŞAN, L.** Procedeu de fabricare a sarmalelor moldoveneşti conservate. Brevet acordat MD 33 din 2008.11.24.

Patent Applications:

1. ŞLEAGUN, G., **IUȘAN, L.,** CASTRAVEȚI, L., TOFAN, S., GOLUBI, R., CUPCEA, T. Procedeu de obţinere a snack-urilor structurate de fructe cu conținut ridicat de compuși polifenolici bioactivi – cerere de brevet de invenție de scurtă durată nr. 2575 din 2024.08.28

ADNOTARE

IUȘAN Larisa: „Argumentarea științifică și elaborarea tehnologiilor de fabricare a produselor alimentației sănătoase în baza materiei prime autohtone", teză de doctor habilitat în științe inginerești, Chișinău, 2025.

Structura tezei: Teza de doctor habilitat constă din introducere, 6 capitole, concluzii şi recomandări, lista lucrărilor citate, 19 anexe. Textul de bază conţine 220 de pagini, 77 de figuri, 64 de tabele. Bibliografia cuprinde 285 referinţe. Rezultatele obţinute sunt publicate în 41 de lucrări ştiinţifice.

Cuvinte-cheie: Alimentaţie sănătoasă, compuşi bioactivi, fibre alimentare, proprietăţi funcţionale, extrudare, valoare nutritivă sporită, culturi cerealiere, materia primă secundară, pectine slab metilate, pectine înalt metilate, metale toxice.

Domeniul de studiu: 253.01 – Tehnologia produselor alimentare de origine vegetală .

Scopul lucrării: Elaborarea principiilor științifice și aplicative pentru implementarea tehnologiilor inovative în fabricarea produselor alimentare sănătoase, bogate în fibre alimentare, prin utilizarea optimă a materiilor prime autohtone.

Obiectivele lucrării: Selectarea și caracterizarea materiilor prime cu potențial nutrițional și funcțional ridicat, în conformitate cu cerințele actuale de alimentație sănătoasă; Optimizarea rețetelor alimentare prin aplicarea metodelor moderne de modelare matematică și inovare tehnologică; Investigarea influenței parametrilor tehnologici asupra calității nutriționale, funcționale și senzoriale a produselor alimentare; Aplicarea tehnologiilor avansate de procesare în scopul păstrării compușilor bioactivi și a valorii nutritive, Evaluarea compoziției fizico-chimice, microbiologice, senzoriale și a stabilității produselor în condiții reale de păstrare; Estimarea bioaccesibilității compușilor bioactivi prin metode in vitro și analiza impactului potențial asupra sănătății consumatorului; Elaborarea schemelor tehnologice și a documentației normativ-tehnice pentru implementarea industrială a produselor alimentare dezvoltate.

Noutatea și originalitatea științifică: Au fost dezvoltate tehnologii inovative de fabricare a produselor alimentare funcționale, destinate alimentației sănătoase, cu un conținut înalt de fibre alimentare, prin valorificarea eficientă a materiilor prime vegetale, cerealiere și a subproduselor agroalimentare. Pentru prima dată a fost aplicată o metodă diferențiată de evaluare a calității, prin compararea cu un model etalon utilizând indicatorii unității de calitate (Pi), pentru caracterizarea completă a acestor produse. În mod inovator, a fost investigată influența componentelor din fructe, legume și plante medicinale asupra fixării cationilor metalici de către pectine, demonstrându-se că acestea pot intensifica, reduce sau nu influența procesul de fixare. Totodată, a fost propus un mecanism de fixare a cationilor metalici prin pectine în compoziții policomponente și elaborată o metodă de estimare a compatibilității pectinei cu ingredientele vegetale, cu scopul eliminării metalelor toxice din organismul uman. Pe baza acestor rezultate, au fost formulate principii de construire a produselor alimentare funcționale cu proprietăți prestabilite și dezvoltate suplimente alimentare biologic active pe bază de pectină, destinate detoxifierii organismului, inclusiv de radionuclizi. Aceste inovații au fost validate în cadrul sistematizării și dezvoltării de noi produse alimentare cu valoare adăugată.

Semnificația teoretică: Lucrarea fundamentează științific parametrii optimi ai procesului de extrudare pentru materii prime vegetale bogate în fibre, corelând compoziția și structura acestora cu condițiile de procesare. Cercetarea a condus la formularea unor principii privind selecția rațională a materiilor prime și ajustarea variabilelor tehnologice (temperatură, umiditate, timp, viteză), în scopul maximizării valorii funcționale și nutriționale a produselor. Rezultatele contribuie la extinderea cunoștințelor în ingineria proceselor alimentare și oferă un cadru teoretic pentru dezvoltarea de produse sănătoase cu profil nutrițional optimizat.

Valoarea aplicativă a lucrării: Rezultatele obținute evidențiază o abordare inovatoare în valorificarea resurselor vegetale și secundare pentru dezvoltarea de produse funcționale cu valoare nutrițională și terapeutică. Soluțiile propuse contribuie la diversificarea alimentelor sănătoase și reducerea riscurilor legate de metale toxice, având un impact practic și științific important pentru transferul în industrie și promovarea unui sistem alimentar durabil.

Implementarea rezultatelor științifice a fost realizată prin testarea tehnologiilor de fabricare a produselor extrudate pe bază de cereale și materii prime secundare în cadrul întreprinderilor „Policom-Prim" SRL și „BIOCOM" SRL din Chișinău. Au fost elaborate acte normative pentru suplimente alimentare biologic active (SABA) cu rol dezintoxicant și produse funcționale derivate, testate la „CONSULT LC" SRL în condiții experimentale și semi-industriale. Aplicarea acestora contribuie la dezvoltarea alimentelor funcționale, susținerea sănătății publice și creșterea competitivității sectorului agroalimentar din Republica Moldova.

ANNOTATION

IUȘAN Larisa: "Scientific Argumentation and Development of Technologies for the Production of Healthy Food Products Based on Local Raw Materials," doctor habilitat thesis in engineering sciences, Chișinău, 2025.

Thesis structure: The doctoral thesis consists of an introduction, 6 chapters, conclusions and recommendations, a list of cited works, and 19 appendices. The main text comprises 220 pages, including 77 figures and 64 tables. The bibliography includes 285 references. The results have been published in 41 scientific papers.

Keywords: Healthy nutrition, bioactive compounds, dietary fiber, functional properties, extrusion, enhanced nutritional value, cereal crops, secondary raw materials, low-methoxyl pectin, high-methoxyl pectin, toxic metals.

Field of Study: 253.01 – Technology of Food Products of Plant Origin.

Research Goal: The development of scientific and practical principles for the implementation of innovative technologies in the production of healthy food products, rich in dietary fibers, through the optimal use of domestic raw materials.

Research Objectives: Selection and characterization of raw materials with high nutritional and functional potential, in line with current healthy nutrition standards; Optimization of food formulations through modern mathematical modeling and technological innovation; Investigation of the influence of technological parameters on the nutritional, functional, and sensory quality of food products; Application of advanced processing technologies to preserve bioactive compounds and nutritional value; Evaluation of physicochemical, microbiological, sensory properties, and product stability under real storage conditions; Estimation of bioaccessibility of bioactive compounds through in vitro methods and analysis of their potential health impact; Development of technological schemes and normative-technical documentation for industrial implementation of developed food products.

Scientific Novelty and Originality: Innovative technologies for manufacturing functional food products, intended for healthy nutrition, with a high content of dietary fiber, were developed, through the efficient utilization of vegetable, cereal raw materials and agro-industrial by-products. For the first time, a differentiated method of quality assessment was applied, by comparison with a standard model using quality unit indicators (Pi), for the complete characterization of these products. In an innovative way, the influence of components from fruits, vegetables and medicinal plants on the fixation of metal cations by pectins was investigated, demonstrating that they can intensify, reduce or not influence the fixation process. At the same time, a mechanism for the fixation of metal cations by pectins in multicomponent compositions was proposed and a method for estimating the compatibility of pectin with vegetable ingredients was developed, with the aim of eliminating toxic metals from the human body. Based on these results, principles for constructing functional food products with predetermined properties were formulated and biologically active pectin-based food supplements were developed, intended for detoxification of the body, including radionuclides. These innovations were validated within the framework of the systematization and development of new food products with added value.

Theoretical Significanceresides in the scientific substantiation of optimal extrusion parameters for fiber-rich plant materials, by correlating their composition and structure with processing conditions. Principles were formulated for rational raw material selection and adjustment of variables such as temperature, humidity, time, and extrusion speed, to enhance the functional and nutritional value of the final products. These findings contribute to the advancement of knowledge in food process engineering and provide a theoretical foundation for the development of optimized, health-promoting food products.

Practical Value of the Research lies in the innovative approach to utilizing plant-based and secondary resources for the creation of functional foods with high nutritional and therapeutic potential. The proposed solutions support the diversification of healthy food products and reduce risks related to toxic metals, offering significant scientific and industrial benefits for promoting a sustainable food system.

Implementation of Scientific Results through testing and validating extrusion technologies using cereal-based and secondary raw materials at "Policom-Prim" SRL and "BIOCOM" SRL in Chișinău. Technical standards were developed for detoxifying BADS and related functional food products, and tested at "CONSULT LC" SRL under experimental and semi-industrial conditions. These implementations contribute to the advancement of functional food production, support public health, and strengthen the competitiveness of the agri-food sector in the Republic of Moldova.

IUȘAN LARISA

SCIENTIFIC ARGUMENTATION AND DEVELOPMENT OF TECHNOLOGIES FOR THE PRODUCTION OF HEALTHY FOOD PRODUCTS BASED ON LOCAL RAW MATERIALS

253.01. Technology of Food Products of Plant Origin

Summary of the doctor habilitat thesis in engineering sciences

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