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Approaches to Developing New Complex Meat Products with Preset Qualitiy

Alexei S. Miroshnik[1,*], **Ivan F. Gorlov**[1,2], **Marina I. Slozhenkina**[1,2]

[1] *Volga Region Research Institute of Manufacture and Processing of Meat-and-Milk Production, Volgograd, Russia*

[2] *Volgograd State Technical University, Volgograd, Russia*

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**Alexei S. Miroshnik: AlexMiroshnik.de@gmail.com, https://orcid.org/0000-0002-8817-6435*
Ivan F. Gorlov: https://orcid.org/0000-0002-8683-8159
Marina I. Slozhenkina: https://orcid.org/0000-0001-9542-5893

Abstract.
A profitable meat-processing business relies on the rational use of its resources, which, in its turn, depends on the constant improvement of product formulations and development of new ones. These operations involve advanced analytical methods and complex approaches. The article introduces a review of modern technical solutions, methods, and approaches to modeling new complex meat products with preset quality indicators.

The review (1990–2022) involved research articles published in high-rated peer-reviewed research journals, educational literature, digital theses published by Russian Dissertation Councils, and patents registered by the Institute of Industrial Property.

The synchronic and diachronic analysis of basic principles of food product design and parametric modeling revealed no universal methodology for meat products development, both in terms of goals and applicability to different meat products types. Forecasting of finished meat products quality indicators requires relevant and accurate information, which is highly variable and fast-changing. Unfortunately, advanced information technologies are slow to adapt to the urgent tasks of the food industry.

As a result, the current methods for developing new complex meat product formulations are useless when meat producers have no access to relevant and self-updating databases on raw materials properties.

Keywords. Food combinatorics, mathematical modeling, digital twin, structural and parametric optimization, cyclic approach, mathematical programming, biological value

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Подходы к проектированию рецептур мясных продуктов с заданными показателями качества

А. С. Мирошник[1,*], И. Ф. Горлов[1,2], М. И. Сложенкина[1,2]

[1] *Поволжский научно-исследовательский институт производства и переработки мясомолочной продукции, Волгоград, Россия*

[2] *Волгоградский государственный технический университет, Волгоград, Россия*

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**А. С. Мирошник: AlexMiroshnik.de@gmail.com, https://orcid.org/0000-0002-8817-6435*
И. Ф. Горлов: https://orcid.org/0000-0002-8683-8159
М. И. Сложенкина: https://orcid.org/0000-0001-9542-5893

Аннотация.
Рациональное использование ресурсов мясоперерабатывающего предприятия является основой для поддержания высокого уровня рентабельности производства и зависит от постоянного совершенствования существующих рецептур мясных продуктов и разработки новых. Эффективное выполнение этих задач возможно при использовании аналитических методов, а также комплексного и системного подходов. Рассмотрели особенности, недостатки и преимущества современных технических решений, методов и подходов к моделированию поликомпонентных мясных продуктов с заданными показателями качества.
Изучили научные статьи рецензируемых ведущих научных изданий, учебно-методические материалы, научно-исследовательские работы, опубликованные в электронном виде диссертационными советами Российской Федерации, и объекты интеллектуальной собственности, размещенные в открытых реестрах Федерального института промышленной собственности, в период 1990–2022 гг. по изучаемой теме.
Представили описание основных принципов проектирования пищевой продукции и особенностей параметрических моделей, используемых для описания пищевых систем. Установили отсутствие универсальной методики разработки мясной продукции как в аспекте применимости к различным видам поликомпонентных мясных продуктов, так и целей проектирования.
Ни один из разработанных методов проектирования рецептурного состава многокомпонентных мясных систем без наличия фактической информации о показателях сырья из-за их высокой вариабельности в реальных условиях, а также медленной адаптации передовых информационных технологий под задачи пищевой промышленности не позволяет достичь высокого уровня точности прогнозирования качественных показателей готовой продукции. Создание общедоступной, подробной и постоянно обновляющейся базы данных по показателям качества сырья могло бы частично решить эту проблему.

Ключевые слова. Пищевая комбинаторика, математическое моделирование, цифровой двойник, структурно-параметрическая оптимизация, циклический подход, математическое программирование, биологическая ценность

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Introduction

Meat processing needs new effective and universal methods to increase its profitability. As a rule, such methods are based on a rational use of enterprise resources. Currently, the food industry tackles this urgent issue by updating the range of food products.

However, new formulations are short-lived because they fail to keep pace with the rapidly changing market conditions. Quite often, even the most advantageous food formulations fail to meet the physiological needs of professional or age communities. They have to be updated in accordance with the discoveries made by nutrition science, which keeps finding new raw materials and ingredients, including structure formers [1–5]. Some authors report a general trend towards expanding the range of products that are totally different from those in current circulation [6–9]. Thus, meat producers have two options: either they create new products or they modify conventional formulations. The first option results in high costs and long trials. The second is associated with the specifics of food systems: for old formulations to be improved, new ingredients require sophisticated mathematical dependencies for quality and quantity key indicators [10, 11].

Complex products are difficult to develop as they require advanced analytical methods. Product costing depends the ever-changing consumer demands, methods of obtaining meat raw materials, seasonal or regional quality fluctuations for each ingredient, etc.

Programming food quality indicators is connected with a large number of indicators to be optimized. These days, this process is totally digital, which means that food technologists have to possess various scientific skills in such spheres as: software engineering, mathematical programming, biochemistry, microbiology, nutrition, and rheology.

Therefore, only integrated and systematic approaches can optimize and update the commercial range of meat products. In this regard, the development of new food formulations with predetermined properties remains a relevant research issue.

This article reviews modern methodological approaches to modeling complex meat products with preset qualities.

Study objects and methods

The review involved standard methods of literature search. The research materials included the following publications released in 1990–2022:

– reviews and research articles published in scientific journals and proceedings of international conferences indexed in Scopus, Web of Science Core Collection, and eLIBRARY.RU;
– educational literature;
– online versions of Russian dissertations and theses; and
– patents registered on the website of the Federal Institute of Industrial Property.

The target audience is food industry workers. As a result, the review relied on publications that featured complete and applied research and covered neither popular science nor non-reviewed editions, whose reliability cannot be guaranteed.

Results and discussion

Most contemporary design methods for balanced meat products are based on the following principles formulated by Academician N.N. Lipatov, Russian Academy of Agricultural Sciences, back in 1990:

– a rationally balanced food product is a set of rationally balanced raw ingredients and materials;
– an optimal formulation for a protein-containing product is based on such a ratio of protein-containing components that provides the most balanced amino acid composition in relation to a statistically valid reference protein;
– the fatty acid composition can be changed by introducing fat-containing ingredients;
– an optimal formulation is based on such a ratio of fat-containing ingredients that provides an optimal ratio of saturated, mono-, and polyunsaturated fatty acids;
– a new formulation is part of a diet; hence, food designers should consider the composition of other dishes and products that will be consumed together with the one they are designing; and
– an optimal complex product has such a component composition that balances the daily diet in terms of biological value, calories, and ballast components [12–15].

These principles are universal, but their practical implementation is difficult because it depends on the product, optimization task, nutrition laws, and food chemistry [16–19].

A new food product has a pre-planned sensory profile, functional characteristics, technological properties, nutritional and biological value, etc. Logically, food product development is impossible without mathematical modeling and advanced information technologies, which, in their turn, require a parametric description and numerical expression of product characteristics [14, 16, 20, 21]. Meat product development also requires a comprehensive assessment of food safety and culinary properties [21]. Nikitina *et al.* developed the following set of parameters for meat product design (Table 1) [20].

More recent studies also put stress on the anti-alimentary and minor food components. For instance, Nugmanov added to this list such concepts as component entropy and energy value entropy, which reflect the degree of uncertainty about the presence of a particular component in the product composition [23].

When designing a new formulation for a meat product, all these parameters can be optimized by using parametric models [24]. According to Donskikh *et al.*, a hierarchical approach to food design should be object-oriented [25].

Ways to achieve the targeted quality of a new meat product differ in the following methods: selecting objective functions and limits; optimization; calculating indicators of biological protein value; calculating technological losses, interaction of micronutrients, and anti-nutritional factors; recording the chemical form of micronutrients; and developing the required structural and sensory properties.

No classification of such methods has been developed so far. However, the following trend is obvious: the younger the method, the more quality indicators it can optimize. This correlation is associated with new nutritional concepts and the growing digitalization of the food industry [20, 26–31]. As a result, this review covers contemporary methods only.

Nikitina *et al.* developed a design algorithm for complex meat products [14]. It gives a calculation sequence for the following chemical composition indicators:

Table 1. Meat product parametric description

Таблица 1. Параметрическое описание мясного продукта

Indicator group	Parameter
Organoleptic properties	Sight
	Smell
	Color
	Taste
	Juiciness
	Consistency
Energy value	Biological oxidation
Biological value	Protein content and amino acid composition
	Macro- and microelements
	Vitamins
	Carbohydrates and their composition
	Moisture content and water activity
	Fat content and composition
Safety	Microbial content
	Ballast content
	Toxins
	Chemical compounds caused by technological processing or storage
Culinary	Processing capacity
	Processing degree
Functional and technological	Water holding capacity
	Fat-binding capacity
	pH
	Plasticity
	Tenderness
Structural and mechanical characteristics	Water-binding capacity
	Protein content and state
	Fat content and state
	Content of connective tissue and tendons
	Texture
	Structure

1) system analysis and formulation ingredients;
2) proteins, fats, and carbohydrates;
3) amino and fatty acids;
4) energy value;
5) amino acid score for the main essential amino acids; and
6) utility factor and comparable redundancy.

Product development relies on software with a relevant database of fatty acid profiles for various products. In a more recent study, Nikitina & Sus added the stage of calculating the vitamin and mineral composition to the initial the algorithm [20]. However, the authors did not describe the stage of system analysis and ingredient matching. Moreover, the algorithm includes no stage of structural and sensory optimization, which means that the development process will be complicated by a long chain of trials.

Karpov & Portnov adhered to a similar algorithm but stated that the amino acid and fatty acid composition of the new product should comply with individual nutritional and diet requirements [32]. They suggest achieving the optimal physical and chemical parameters by observing the ratios of fats vs. proteins and carbohydrates vs. proteins. However, their scheme also lacked the stage of analysis and ingredient matching.

Obviously, this method is applicable exclusively to the development of food products for client-tailored diets. Its obvious disadvantage is the effort-consuming selection of the variances in quality indicators, as well as in optimal amino acid and fatty acid compositions. Apparently, the only way to optimize the sensory profile of the new product is by numerous test trials.

Razumovskaya *et al.* emphasized the stage of raw material matching [33]. They offered a system that allows food designers to observe specific ratios of all components (Fig. 1).

The concepts of tolerance, stability, solubility, and introduction sequence make it possible to reduce the number of experimental trials. However, the method cannot be used to optimize the cost of raw materials and is quite labor-intensive because the sensory, physicochemical, and toxicological parameters are determined more

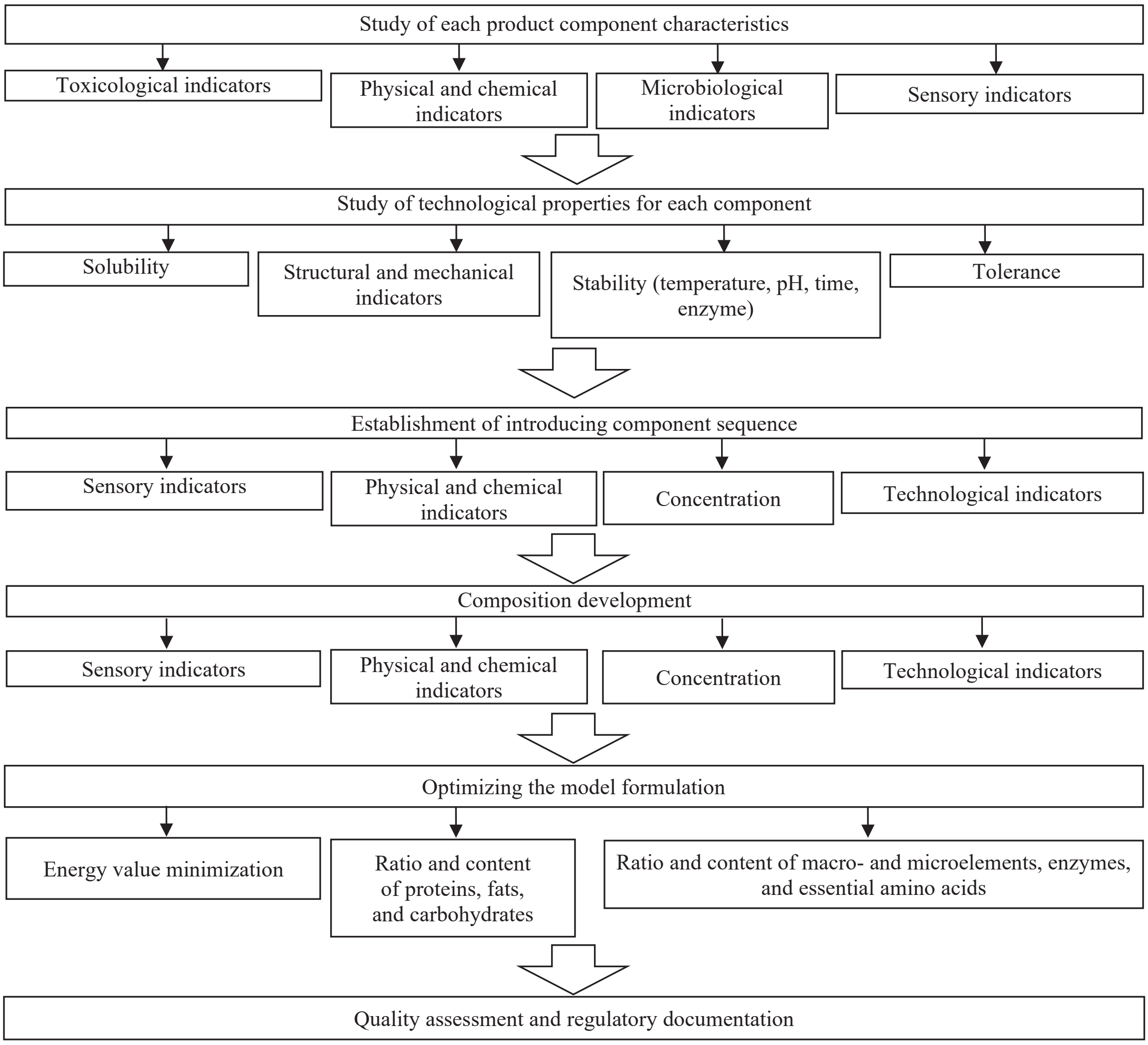

Figure 1. Methodological principles of food product development [33]

Рисунок 1. Методологические принципы проектирования продуктов питания [33]

than once. Moreover, the authors did not explain how to optimize the composition of the model formulation.

Trubina *et al.* adapted the algorithm to therapeutic meat products by introducing the stage of food additives that fortify the new product with micronutrients [35]. The authors stress the high complexity of component matching to provide the specified quality indicators. To solve this problem, they propose to apply mathematical planning, artificial intelligence, multidimensional scaling, cluster analysis, and, most important, data mining.

According to Lisitsyn *et al.*, to achieve the desired properties, food designers should start by specifying the methods of fortification/elimination, food combinatorics, optimization of heat treatment modes, etc. (Fig. 2) [36].

Lisitsyn *et al.* saw enzymatic tenderization, *in vivo* modification, and animal welfare optimization as particularly promising methods for obtaining new functional products [36].

Ursachi *et al.* pursued the same strategy but added some promising food processing technologies, e.g., ultrasonic treatment, high pressure and cold plasma, fortification of meat products with pro- and prebiotics, etc. [37]. In theory, this list could be augmented with radurization and microwave treatment, which are gaining popularity as means of defrosting meat bulks. Despite the extensive methodological and theoretical studies, these technical solutions cannot become mainstream in the domestic meat processing industry and require additional research [38–44].

Kalinin & Potoroko declared the priority of biologically active additives that make food products functional (Fig. 3) [22]. Their approach attached particular importance to the way micronutrients are delivered and chemically transformed in all structural elements of the food matrix during technological processing, storage, and digestion. The algorithm also included

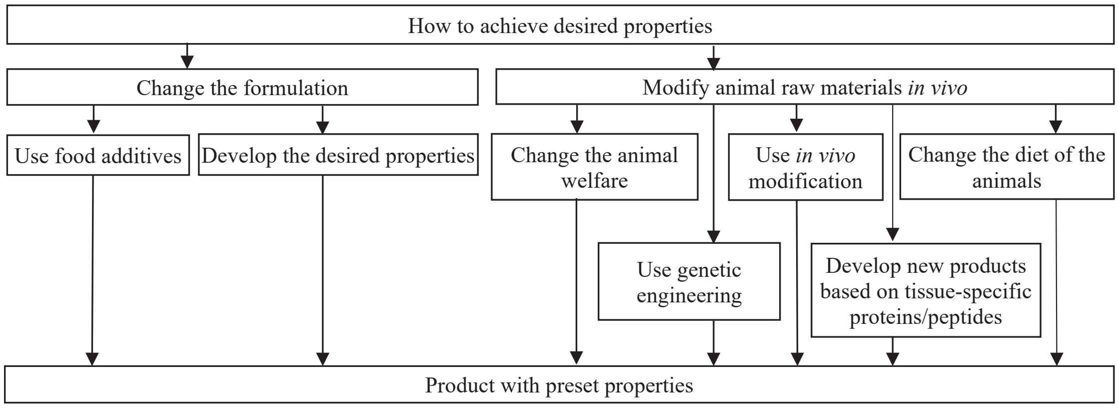

Figure 2. Developing meat products with preset properties [36]

Рисунок 2. Разработка продуктов питания на мясной основе с заданными свойствами [36]

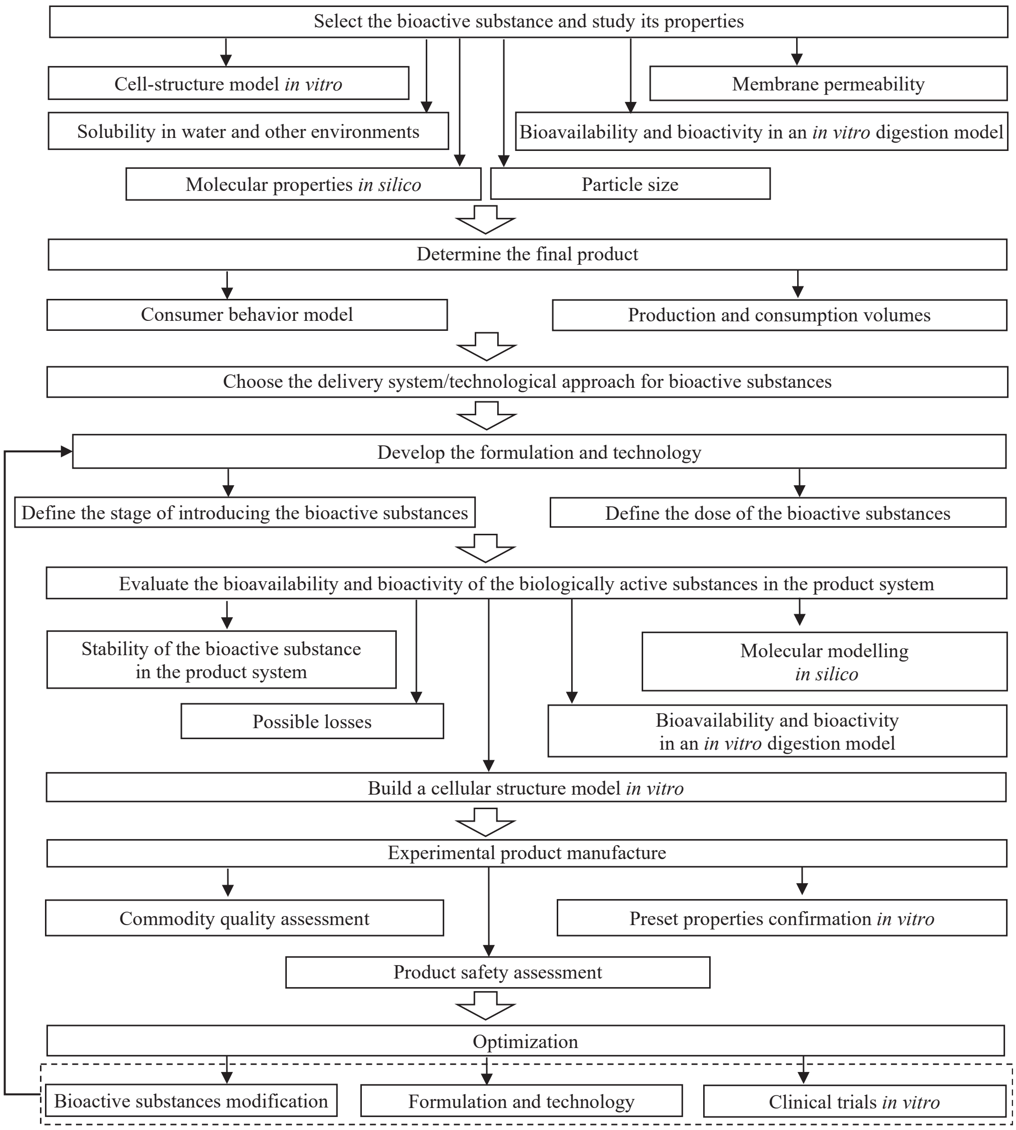

Figure 3. Methodology of integrated approach to healthy food production with proven effectiveness [22]

Рисунок 3. Методология интегрированного подхода производства продуктов для здорового питания с доказанной эффективностью [22]

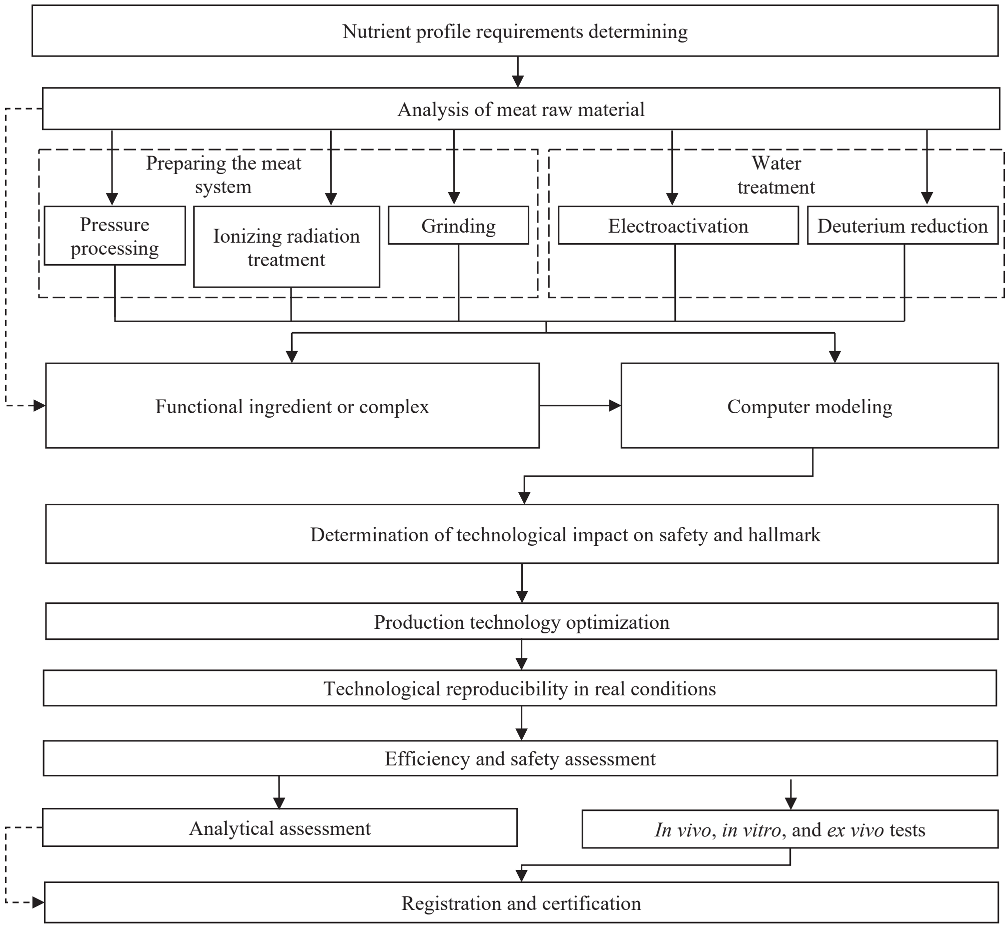

Figure 4. Methodology of functional meat products development [33]

Рисунок 4. Методология создания функциональных мясных продуктов [33]

the market promotion stage. The disadvantage of this approach is in the high economic costs of establishing the effectiveness of fortified foods.

Chemical and physiological compatibility of all ingredients is usually achieved by assessing the bioavailability and bioactivity of biologically active substances. Apparently, this stage presupposes determining the ingredient composition of the product under development. However, the scheme proposed by Kalinin & Potoroko postpones the formulation until the very final stage [22]. As a result, the only way to optimize the new formulation is either to appeal to an existing formulation or to modify a basic one, which is the main disadvantage of this algorithm.

Still, the method might appear quite effective for tailored diets. It is, however, hardly applicable to mass consumption products because the multiple trials and product tests are expensive. Again, the authors failed to explain the optimization of structural properties, sensory profile, and material costs.

According to Dydykin, the degree to which the product satisfies human physiological needs can be defined by assessing the nutrient potential of raw materials, their processing, and functional ingredients [34]. The nutrient profile of the new product depends on the biological value of the diet. Figure 4 illustrates another methodology for developing functional meat products.

Sijtsema *et al.* and Saguy & Taoukis offered a cyclic approach to product development as an alternative to the linear one [45, 46]. The cyclic approach presupposes a continuous interaction with consumers, resulting in a progressive product improvement. This algorithm makes it possible to identify the real consumer perception and avoid the subjectivity factor. However, it is consumer properties that are improved, not the biological value. If the product is not in demand, and the meat producers receives no feedback from customers, they have no data to improve the product.

Nikitina eliminated these disadvantages by focusing her method on a specific consumer or target group: in general, product development should follow diet development (Fig. 5) [12].

The method offered by Nikitina implies the optimization of structural, mechanical, functional, and tech-

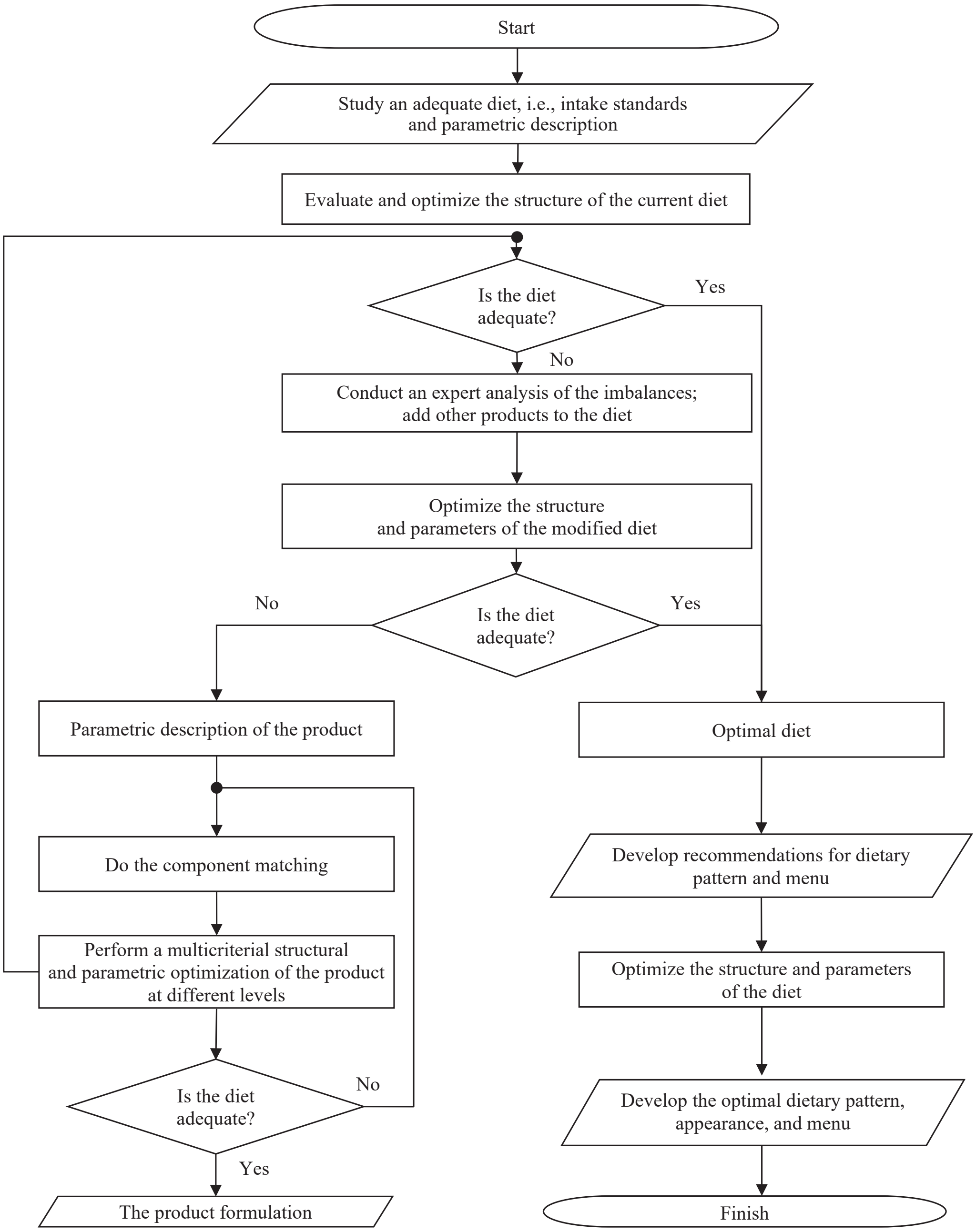

Figure 5. Algorithm for structural-parametric optimization [12]

Рисунок 5. Диалоговый алгоритм структурно-параметрической оптимизации [12]

nological indicators of the food system [12]. The search for optimal solutions employs mathematical models that reflect the functional relationships between the abovementioned indicators of raw ingredients and finished products, including the economic perspective. Product development relies on a digital twin, which copies the structural, functional, and technological properties of the ingredients, as well as the biochemical and colloidal kinetics that define the patterns of behavior of food systems triggered by the changes in various physical and chemical factors. Computer modeling predicts the energy, moisture, fat, carbohydrates, vitamins, microelements, proteins, and biological value in the designed product. Virtual imitations and trials help to choose the optimal formulation.

This approach needs no actual experimental trials, which makes it quite economical. On the other hand, it requires a constant update of factual information about the quality indicators of raw materials. If the software is integrated into a corporate information network, it needs an extensive database on the kinetics of biochemical and colloid-chemical processes.

Tailored approach to food development was also reported by Di Renzo *et al.*, Prosekov, and Prosekov *et al.*, who described a new scientific branch of omic science, which covers nutrigenetics, nutrigenomics, and proteomics [47–49]. It studies the relationship between food-related diseases and changes in human genotype and food preferences, the effect of various substances on genome, etc. These studies stress the importance of using nutrigenetic testing in food product development.

Conclusion

In case of complex meat systems, holistic forecasting depends on a great number of quality indicators, which require application of modern software. Effectiveness of approaches to formulating new meat products reviewed in this article depending on technology level of such advanced technologies. The current shortage of domestic software caused by the emigration of IT specialists hinders the introduction of technological solutions into meat product development.

Accurate forecasting of meat product quality requires relevant information about the actual physical, chemical, technological, and other indicators that characterize the behavior patterns of heterogeneous dispersed meat systems and their functional interrelationships. Meat producers can obtain this information either by collection data in real time or using existing datasets. The first option demands a thorough incoming control of raw materials within production process or in cooperation with third-party organizations, which inevitably reduces the profitability. In this case, software integrated into the corporate information network can solve the problem. The second option is currently unavailable because most datasets are not publicly available or lacking. We offer the following solution: advanced express analysis equipment based on artificial intelligence or dynamic image analysis and free public databases updated by its users, like Wikipedia.org. In this case, even small meat processing plants will gain access to effective methods for modeling meat product formulations, which will raise their domestic and global competitiveness.

Contributions

The authors were equally involved in writing the manuscript and are responsible for any potential cases of plagiarism or self-plagiarism.

Conflict of interest

The authors declare that there is no conflict of interest regarding the publication of this article.

Критерии авторства

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Конфликт интересов

Авторы заявляют об отсутствии конфликта интересов в связи с публикацией данной статьи.

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