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ASSESSMENT AND PROSPECTS OF PROBIOTIC POTENTIAL IN FUNCTIONAL MEAT-BASED NUTRITION PRODUCTS

Probiotic food products represent one of the most rapidly growing categories in the functional nutrition market. While probiotic strains have been successfully applied in the dairy, cereal, bakery, and juice industries, their use in the production of fermented meat products remains limited. The main challenge lies in the specific characteristics of the meat matrix: although the absence of heat treatment favors probiotic survival, factors such as high salt content, low pH, and reduced water activity can significantly impair the viability of microorganisms.

This article reviews current scientific approaches to the development of meat products with probiotic properties. The probiotic potential of various lactic acid bacteria strains used in meat processing technologies is analyzed. The prospects for incorporating probiotic cultures into both traditional and innovative meat products are discussed, with the aim of enhancing their biological value and functional orientation. Particular attention is given to issues of microbiological safety, maintenance of probiotic viability, and the potential health benefits of such products.

Keywords: probiotics, meat products, functional nutrition, lactic acid bacteria, fermentation, biological value, microbiota.

Introduction

Probiotic food products represent one of the most rapidly evolving categories within the functional food sector. Currently, probiotic microorganisms are successfully applied in the production of dairy products, cereal-based foods, bakery goods, and fruit and vegetable juices [1].

Despite their strong traditional background and potential as carriers of probiotic microorganisms, fermented meat products remain underrepresented among functional foods compared to other food matrices.

The commercial application of probiotic strains in fermented meat products still faces several technological challenges. On the one hand, meat matrices offer certain advantages for maintaining probiotic viability, as the production process typically excludes thermal treatment. On the other hand, unfavorable environmental factors – such as high salt concentration, reduced pH, and low water activity – ca inhibit the growth and survival of probiotic microorganisms.

Another complicating factor is the presence of native microbiota in raw meat, which may compete with the introduced probiotic strains and affect the microbial composition of the final product [2].

One promising solution is the use of microorganisms adapted to the meat environment that demonstrate both technological stability and distinct probiotic properties. These bacteria can be isolated from traditional fermented meat products or derived from existing commercial starter cultures used in meat processing. An alternative strategy involves incorporating strains with documented probiotic effects into starter cultures specifically adapted to meat matrix conditions.

Starter cultures are defined as single or mixed microbial preparations applied at known concentrations to initiate and conduct fermentation in meat products. The use of such cultures offers a number of advantages over spontaneous fermentation, including improved process control, reduced ripening time, inhibition of pathogenic microorganisms, and enhanced reproducibility of product quality across production batches [3].

However, selecting an effective starter culture for functional meat product development remains a complex task, requiring a thorough evaluation of the biotechnological properties of the candidate strains.

Microorganisms used as starter cultures include bacteria, yeasts, and molds. Among them, lactic acid bacteria (LAB) are the most widely employed group in the fermentation of both meat and dairy products [4].

Despite increasing scientific interest and potential benefits, probiotic meat products remain a relatively novel and underexplored field. The primary challenge is achieving a balance between technological requirements (including safety, stability, and sensory attributes) and the preservation of probiotic functionality.

This review thus explores the key technological opportunities, biotechnological constraints, quality characteristics, and potential risks associated with the development and consumption of probiotic meat products within the framework of functional nutrition.

The aim of this review is to systematize current scientific knowledge regarding the probiotic potential of meat products and to analyze the prospects for their integration into the functional food sector. Particular attention is paid to identifying priority biotechnological and applied research directions in this field.

Materials and methods

The methodology of this study was based on principles commonly applied in systematic reviews. To assess the probiotic potential of fermented meat products, a literature search was conducted for publications from 2018 to 2025 using the databases PubMed, ScienceDirect, Google Scholar, and the Cochrane Library. The following keywords were used: *probiotic meat products, fermented meat, LAB in meat, functional foods.*

Peer-reviewed articles describing laboratory, clinical, and industrial studies were included, provided they contained data on the application of probiotic cultures in meat products, their viability, and their impact on quality and functional properties.

Initial screening was performed based on titles and abstracts, followed by full-text analysis. As a result, 30 publications were selected that reflect current scientific approaches to the use of probiotics in the meat industry and their potential within the context of functional nutrition.

Results and discussion

Probiotics are live microorganisms that, when administered in adequate amounts, confer health benefits on the host – a definition supported by international expert organizations. Within fermented food products, probiotic microorganisms can exert a wide range of physiologically significant effects, including the normalization of gut microbiota, modulation of the immune response, and prevention of various chronic diseases [5].

In this context, probiotics are classified as functional food components capable of providing additional health benefits beyond the basic nutritional value of the product. According to analytical forecasts, the global market for functional foods is showing a steady growth trend, with an expected compound annual growth rate (CAGR) of 8.5 % from 2022 to 2030. This is largely driven by increasing consumer interest in healthy lifestyles and preventive nutrition. Fermented meat products are considered a promising and emerging segment of probiotic food, demonstrating consistent growth since 2018 and showing potential for expansion within the functional food and beverage category (Fig. 1) [6].

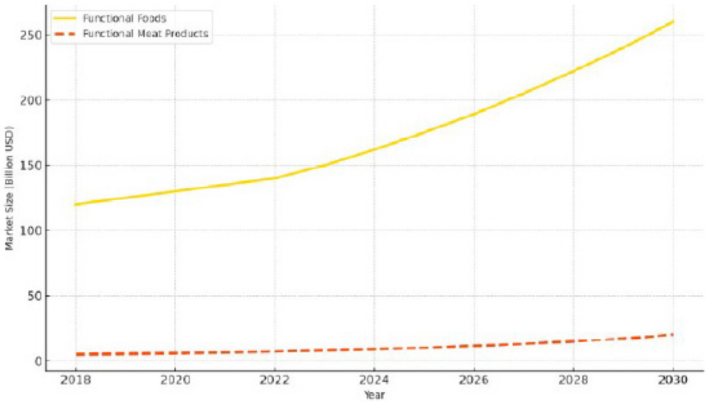

Figure 1 – Growth of the global market for functional foods and functional meat products [6]

One of the key and consistent areas of application for starter cultures in the meat industry is ensuring product preservation, which is accompanied by recognized technological advantages, including microbiota stabilization, improved safety, and the development of characteristic organoleptic properties. Depending on technological requirements and consumer preferences, different strains are used in various products.

Lactic acid bacteria of the genera *Lactobacillus, Pediococcus, Leuconostoc, Lactococcus,* and *Enterococcus* are widely employed as starter cultures in the production of fermented meat products. Their primary role lies in reducing pH through the production of lactic and acetic acids during glycolysis, which contributes to color stabilization, suppression of pathogenic microflora, and development of the characteristic flavor of fermented meat [7].

Some strains, such as *Lactobacillus plantarum* and *Lactobacillus acidophilus,* are capable of producing bioactive peptides during fermentation and ripening, thereby enhancing the functional value of the product. As a result, the color intensity of the meat product improves, the growth of pathogenic microorganisms is inhibited, and a typical aroma and flavor of dry-cured meat is developed. At the same time, lactic acid bacteria contribute to acidification of the environment, providing additional potential probiotic effects [8].

Lactic acid fermentation has a significant impact on the development of the product's flavor profile through the production of organic acids and the activation of proteolysis and lipolysis processes. These processes lead to the release of flavor-forming compounds, including fatty acids, peptides, amino acids, and aldehydes [9].

Studies by Tukel O. and Sengun I. demonstrated that the use of probiotic cultures in the production of fermented salami contributes to improved sensory characteristics such as flavor and color. Additionally, these cultures positively affect texture by enhancing proteolysis, increasing water-holding capacity, and reducing toughness during ripening [10].

According to the research of Lahiri D. et al., the use of starter cultures promoted standardization of the technological process and prevention of manufacturing defects. A major advantage was the enhancement of microbiological safety in fermented meat products, which was attributed to the production of several antimicrobial metabolites, including lactic, acetic, propionic, and benzoic acids, hydrogen peroxide, and bacteriocins – proteinaceous compounds with strong bactericidal properties (Fig. 2) [11].

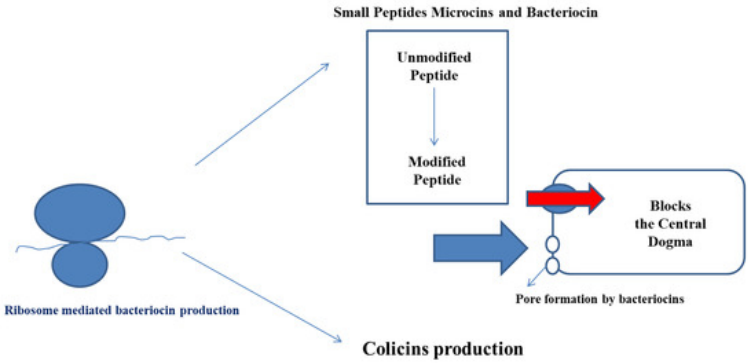

Figure 2 – Mechanism of action of bacteriocins in inhibiting the growth of other microorganisms [11]

Numerous studies have demonstrated the antagonistic properties of various strains of lactic acid bacteria (LAB) against pathogenic microorganisms.

According to the study by Di Gioia et al., *in vitro* experiments confirmed the antagonistic activity of *Lactiplantibacillus plantarum* and *Lactobacillus delbrueckii* against *Clostridium perfringens* and other *Clostridium* species [12].

Wang et al. reported that bioactive peptides produced by LAB – particularly *Lactiplantibacillus plantarum* and *Lactobacillus acidophilus* – exhibit pronounced antimicrobial properties capable of inhibiting the growth of both spoilage microorganisms and pathogens, including *Listeria monocytogenes, Staphylococcus aureus,* and *Salmonella spp.* [13].

It is important to emphasize that the competitiveness of starter cultures against the natural microbiota of raw meat, as well as their ability to perform targeted metabolic functions, depends on their growth rate and resistance to specific conditions of fermented meat products. These include an anaerobic environment, NaCl concentration, ingredient composition, fermentation and ripening temperatures, and low pH levels [14].

Technological components such as salt and thickeners can influence bacteriocin synthesis and the probiotic functionality of certain *Lactobacillus* strains. Additionally, spices may affect the growth dynamics of starter cultures.According to Verluyten J., garlic enhances bacteriocin production, pepper stimulates lactic acid synthesis, whereas nutmeg reduces bacteriocin output. However, the addition of garlic in the production of Turkish sucuk did not significantly affect the survival of *S. typhimurium* [15].

Studies by Sirini et al. demonstrated high viability of starter and probiotic cultures during the fermentation and ripening of fermented meat products when using the probiotic strain *Lactiplantibacillus plantarum* BFL in the production of dry-fermented sausages. It was established that this strain maintained stable viability throughout the drying phase and exhibited pronounced biocontrol properties [16].

Multiple studies confirm that the consumption of fermented meat products containing probiotic cultures may positively affect health. The use of probiotics is associated with various beneficial effects on the human body, including alleviation of lactose intolerance symptoms, stimulation of immune function, improved digestion and intestinal transit, reduced frequency of diarrhea, decreased risk of colorectal cancer, and lowered cholesterol levels [17].

In studies by Manassi et al., daily consumption of 30–50 g of probiotic salami containing strains such as *Lactobacillus acidophilus* LAFTI® L10, *Lactobacillus rhamnosus* HN001, or *Lactobacillus paracasei* LTH 2579 contributed to a reduction in *Listeria monocytogenes* levels in feces, decreased inflammatory markers (e.g., C-reactive protein and tumor necrosis factor-α), and stimulated immune response [18].

According to Holck, A., *Lacticaseibacillus acidophilus*, widely used as a probiotic, can enhance the nutritional and health-promoting value of fermented meat products due to its beneficial effects on gut health [19]. Despite the challenges associated with maintaining probiotic viability during fermentation and ripening, studies by Leeuwendaal, N. showed that *L. acidophilus* exhibited strong resistance to the acidic environment typical of fermented meat matrices. Preserving its activity throughout the production process is critical to achieving the intended functional effects [19].

In research by Schirone, M., strains of *L. crispatus, L. amylovorus, L. johnsonii, L. gasseri,* and *L. acidophilus* were also shown to be highly effective in fermentation, resistant to bile and gastric juice, which minimized their negative impact on intestinal microbiota.

Although lactic acid bacteria (LAB) remain the predominant probiotic microorganisms in the food industry, yeasts have also demonstrated promising functional properties. Yeasts are capable of synthesizing biologically active metabolites with potential nutraceutical and therapeutic value, contributing to the regulation of gut microbiota, exerting antioxidant activity, and participating in the biocontrol of pathogenic microorganisms and toxins. Moreover, yeasts are rarely associated with foodborne infections, which increases their safety for use in functional foods [20].

Studies indicate the probiotic potential of non-*Saccharomyces* and non-*Kluyveromyces* yeast species isolated from fermented food products. In particular, *Debaryomyces hansenii* and *Yarrowia lipolytica*, found in dry-fermented sausages, have shown promising functional properties [18]. It is worth noting that the functional properties of *D. hansenii* may vary depending on the specific strain.

These findings support the notion that probiotic-enriched fermented meat possesses potential functional properties. Furthermore, the synergistic application of probiotic and traditional starter cultures in the production of fermented meat products can ensure not only microbiological safety but also high nutritional value and appealing sensory characteristics of the final product.

Conclusions

Scientific and technological research, along with the development of new probiotic starter cultures adapted to the specific conditions of meat fermentation, open up promising opportunities for the creation of innovative functional meat products that meet the growing demand for healthy and safe nutrition.

The obtained data confirm that microorganisms included in starter cultures are capable of suppressing or reducing the growth of pathogenic bacteria through the production of specific metabolites and competitive exclusion. This allows for a reduction in the use of chemical additives such as nitrites and nitrates.

The inclusion of probiotic cultures in the formulations of fermented meat products represents a promising direction in the field of functional nutrition. Lactic acid bacteria possessing antimicrobial properties and resistance to adverse conditions of the meat matrix are capable of shaping the desired organoleptic characteristics of the product. Strains such as *Lactobacillus plantarum, L. acidophilus, L. gasseri,* among others, exhibit antimicrobial activity, tolerance to technological stress, and probiotic potential.

The use of yeast cultures with biocontrol and nutraceutical potential also remains a promising area of development.

Contemporary studies confirm that the application of probiotics not only improves the quality and microbiological safety of meat products but also enhances their biological value. However, despite the positive results of individual inoculations, further comprehensive research is required to identify dominant microorganisms in probiotic mixtures and to assess their interactions within fermented meat products.

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ФУНКЦИОНАЛДЫ ТАҒАМДАР АЯСЫНДА ЕТ ӨНІМДЕРІНІҢ ПРОБИОТИКАЛЫҚ МҮМКІНДІКТЕРІ МЕН ДАМУ ПЕРСПЕТИВАЛАРЫ

Пробиотикалық азық-түліктер – қарқынды дамып келе жатқан санаттардың бірі. Пробиотикалық штаммдар сүт, дәнді-дақыл, наубайхана және шырын өнеркәсібінде сәтті қолданылып келеді, алайда олардың жетілдірілетін ет өнімдері технологиясында қолданылуы шектеулі күйде қалып отыр. Бұл жағдайдың негізгі себебі – ет матрицасының ерекшеліктеріне байланысты: пробиотиктердің тірі қалуына жылумен өңдеудің болмауы оң әсер етсе де, өнімнің тұз мөлшерінің жоғары болуы, pH деңгейінің төмендігі және ылғалдылық белсенділігінің аздығы микроағзалардың өміршеңдігін төмендетуі мүмкін.

Мақалада пробиотикалық қасиеттері бар ет өнімдерін әзірлеуге қатысты қазіргі ғылыми тәсілдер қарастырылады. Ет өнімдері технологиясында қолданылатын әртүрлі сүт қышқылды бактерия штаммдарының пробиотикалық әлеуетіне талдау жүргізілді. Дәстүрлі және инновациялық ет өнімдерінің құрамына пробиотикалық дақылдарды енгізу арқылы олардың биологиялық құндылығы мен функционалдық бағыттылығын арттыру перспективалары *талқыланды. Микробиологиялық қауіпсіздік, пробиотиктердің тірі қалуын қамтамасыз ету, сондай-ақ мұндай өнімдердің адам денсаулығына әсері мәселелеріне ерекше назар аударылды.*

Кілтті сөздер: пробиотиктер, ет өнімдері, функционалдық тамақтану, сүт қышқылды бактериялар, ферментация, биологиялық құндылық, микробиота.

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ОЦЕНКА И ПЕРСПЕКТИВЫ ПРОБИОТИЧЕСКОГО ПОТЕНЦИАЛА МЯСНЫХ ИЗДЕЛИЙ В КОНТЕКСТЕ ФУНКЦИОНАЛЬНОГО ПИТАНИЯ

Пробиотические продукты питания являются одной из наиболее динамично развивающихся категорий. Пробиотические штаммы успешно применяются в молочной, зерновой, хлебопекарной и соковой промышленности, однако их использование в технологии созревающих мясных изделий остаётся ограниченным. Основным препятствием является специфика мясной матрицы: несмотря на отсутствие термической обработки, благоприятной для выживания пробиотиков, высокое содержание соли, низкий pH и малая водная активность могут снижать жизнеспособность микроорганизмов.

В статье рассматриваются современные научные подходы к разработке мясных изделий с пробиотическими свойствами. Проведён анализ пробиотического потенциала различных штаммов молочнокислых бактерий, применяемых в технологии мясных продуктов. Обсуждаются перспективы интеграции пробиотических культур в состав традиционных и инновационных мясных изделий в целях повышения их биологической ценности и функциональной направленности. Особое внимание уделено аспектам микробиологической безопасности, сохранению жизнеспособности пробиотиков, а также влиянию таких продуктов на здоровье человека.

Ключевые слова: пробиотики, мясные изделия, функциональное питание, молочнокислые бактерии, ферментация, биологическая ценность, микробиота.

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