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Metabiotics in molecular nutrition: history and practice

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Abstract. The human microbiota is formed under the influence of external factors, among which a healthy diet plays a key role. The modern people microbiome changes under human eating behavior, stressful factors, agricultural industrialization, increased environmental load, and alimentary disease risks. The human gut microbiome is recognized as the most important biological interface between human genetics, environment, and lifestyle. Nutrition science is entering a new era of targeted action on the body's metabolic activity through the formation of a healthy microbiome, taking into account men individual nutritional characteristics. The paper presents the design of healthy food product technologies, the molecular concept of food engineering and molecular gastronomy, their relationship with traditional cooking and modern cuisine. Much attention is paid to the description of main components and directions of modern molecular gastronomy development, innovative technologies, and ingredients. The role of dietary fibers, prebiotics and probiotics for the normalization of gastrointestinal tract is indicated from the position of the adequate nutrition theory. Some scientific studies on probiotic and metabiotic effects on gut microbiome are described. Modern advances in food biotechnology allow us to obtain symbiotic microbiological culture consortia for new healthy food product manufacture including molecular gastronomy technologies.

1 Introduction

According to genetic researches of the Israeli scientists [1], up to 98 % of the human microbiota is formed under the influence of external factors, among which a healthy diet plays an important role. The microbiome is a consortium of microorganisms that live in the human body. The microbiome structure includes sustainable microbial communities. Products that are necessary for the microbiome life determine human vital needs in food substances.

The microbiome also determines a person's susceptibility to various diseases. The relationship between the human host and his microbiome is a determining factor in human health formation. The molecular concept of food engineering has contributed to the development of molecular gastronomy based on various fields of food science, traditional cooking, and modern cuisine technologies.

Molecular gastronomy includes four main components: healthy or useful ingredients; physical and biochemical processes in food production; innovative technologies and equipment to obtain food product with new required properties; biotechnological solutions to create healthy food products. Every man should regularly eat food enriched with dietary fiber and useful microflora. Such food includes fermented milk products, fermented vegetables, soaked berries and fruits, functional products enriched with probiotics or metabiotics.

The purpose of this paper was to study the need to use functional food ingredients of microbial origin in modern molecular gastronomy - an innovative trend in food chemistry and technology.

The following questions were studied: role of the human gut microbiota as the most important biological interface between human genetics, environment and lifestyle; the nutrition influence on the human microbiome formation; modern molecular gastronomy development strategies, innovative technologies and ingredients used in healthy food production.

2 Research objects and methods

The research objects were the following: the human microbiome and its effects; functional ingredients used in the food industry; innovative technologies in the food industry. The research was carried out using an analytical method of searching and analyzing the literary data. This method made it possible to systematize the obtained information and to substantiate the importance of microbial origin functional food ingredient use in molecular gastronomy technologies.

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3 Results and discussion

Human nutrition in its present and future has been of interest to scientists throughout the history of the food industry. Avicenna was one of the first one to mention the influence of food on human health. Researches of many Russian scientists, including I. I. Mechnikov, A. N. Beketov, D. V. Kanshin, F. F. Erisman, A. A. Pokrovsky, A. M. Ugolev, V. A. Tutelyan, B. A. Shenderov, E. I. Tkachenko [2] were devoted to finding new opportunities for the healthy food industry development. In the early 1900s, I. I. Mechnikov was the first one to suggest using live microorganisms to maintain gut health and prolong man life. Now the term "probiotic" is used to describe food microbes that can benefit the host's health [3].

Many individual types or combinations of probiotics stabilize inflammatory disease symptoms of the gastrointestinal tract. Although some of these probiotic strains reduce toxic microbial metabolic activity, the recent evidence shows the ability of these organisms to modulate gut immune responses [4].

Since the beginning of the XIX century, the theory and practice of healthy eating have significantly evolved. The first theory of "normal" nutrition by D.V. Kanshin, set out at the end of the XIX century, in the book "Encyclopedia of Nutrition", was balanced by A.A. Pokrovsky in the middle of the XX century. Further it was adapted by A.M. Ugolev, optimized by V.A. Tutelyan, B.A. Shenderov, and generalized into a new holistic nutrition theory by E.I. Tkachenko. Relationships between human health, nutrition and the gut microflora state were studied by many Russian and foreign researchers [5, 6, 7, 8]. Understanding the specific role of the gut microbiota in the health-nutrition chain allows nutritionists and biotechnologists to get a deeper insight into diet influence on human health. Shenderov B.D. [9] emphasizes that the modern human microbiome has changed radically due to the human eating behavior transformation, stress factors, the agriculture industrialization, the environmental load, and alimentary-related disease risks increasing.

The microbiome is a microorganism collection found in the healthy human organism. The microbiome structure includes stable microbial communities. Their metabolic products determine the human needs in food substances and his predisposition to various diseases. The relationship between the host and his microbiome is a determining factor in human health [10, 11]. It is known, that the human organism provides food for millions of bacteria. This bacteria consortium contains ten times more cells than the human organism, and 100 times more genes than the human genome [12, 13]. Immune system disbalance leads to the development of many non-communicable diseases such as autoimmunity, allergies and cancer.

Gastrointestinal tract is the place of interaction between the host's immune system and microorganisms, both symbiotic and pathogenic. Many aspects of adaptive (acquired) immune system development are influenced by the gut microbiome. Scientists are discussing the concept that the human organism microflora disorders could lead to immunological disregulation and would account for inflammatory gut diseases [14].

To reduce the "civilization disease" risks substantially associated with gut microbiota disorders, the human diet should be balanced by addition of functional foods containing probiotics, metabiotics and dietary fibers [9]. The reduction of useful gut microflora concentration results in increased vulnerability of a human organism to pathogens such as E. coli, Shigella, certain types of Streptococcus etc., so the human organism immunity decreases as a result.

Currently the human gut microbiome is recognized as the most important biological interface between human genetics, environment and man lifestyle. An increasing number of foreign companies offer their nutritional recommendations based on deep analysis of the human genome and microbiome, biochemical researches including biomarkers. Leading world scientists show that the symbiotic gut microflora is actively involved in the endogenous synthesis and recycling of many macro- and micro-nutrients, as well as signaling molecules. It also regulates the relationship between eukaryotic and prokaryotic human cells [8].

It is known that the presence or absence of certain microorganisms in the human gut microbiome structure affects the food substance assimilation degree. Thus, the presence of Ruminococcaceae bacteria in gut contributes to a more complete assimilation of starch and allows the human organism to receive additional nutrition from all starchy foods. That is why the ancient man was able to survive during historical periods when food protein sources were limited.

Nutrition science is entering a new era of directed influence on the body's metabolic activity by forming a healthy microbiome, taking into account individual human’s nutritional characteristics, his ancestors, racial, national and ethnic origin, specific ecological and biochemical living environment conditions [8].

Technological aspects of nutrition science are being developed through the introduction of molecular approaches to the healthy food product design. These technologies are inseparably related with food biochemistry (Fig.1).

The molecular concept of food engineering has contributed to the molecular gastronomy development, which is inextricably linked to various fields of food science, traditional cooking and modern cooking technologies.

The history of molecular gastronomy began in the XVIII-XIX centuries [15].

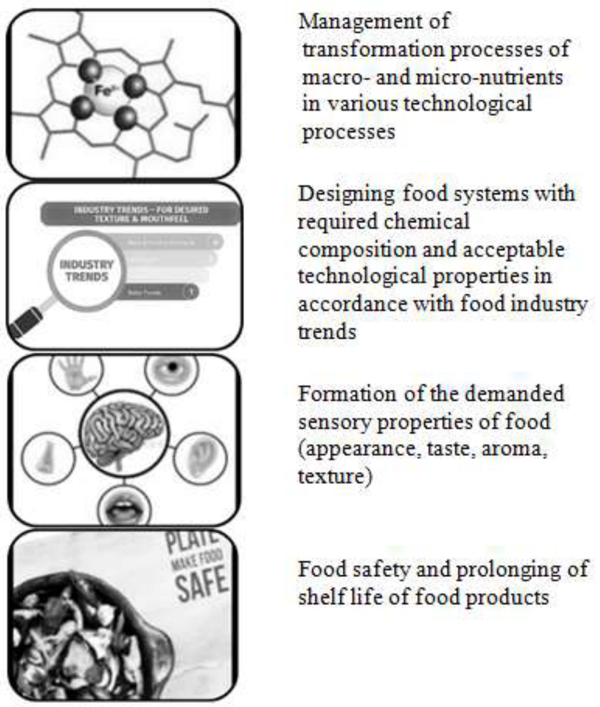

Fig. 1. Molecular principles of food engineering.

Currently molecular gastronomy is a combination of culinary art, food science and technological processes occupied at the molecular level [16, 17].

Modern molecular gastronomy has two components: commercial and technological.

The commercial component includes, for example, the competition between food producers for potential consumers: fast food and haute cuisine restaurants. This is a commercial marketing tool.

The technological component combines innovative technologies of product creation using the principles of food engineering and molecular nutrition, their integration in high-tech food production.

Modern trends in the molecular gastronomy development include:

Management of macro - and micro-nutrient interconversion processes in various technological processes;

Design of food systems with specified properties;

Formation of the required sensory food properties (taste, aroma, texture);

Food safety and prolonging of shelf life of food products.

Thus, molecular gastronomy includes four main components [18]:

The useful ingredients;

The physicochemical and biochemical processes occurring during food product cooking;

The innovative technologies and equipment that provide technological processes for obtaining food product with specified properties;

The biotechnological solutions for creating healthy food products.

Molecular gastronomy includes many combined biotechnologies such as biological methods of food preservation - barrier technologies [19, 20], meat, fish, fruit, vegetable and milk fermentation technologies [21], food raw and product safety [22]. Molecular gastronomy also includes cavitation, vacuum and cryogenic technologies for food processing.

Unfortunately, many refined foods dominate in diets of the population in our days. At the same time the use of dietary fiber is significantly reduced in comparison with the increase of protein and fat product usage [23]. Recent researches by A. M. Valdes [24] showed that low content of dietary fiber and other prebiotic fibers in the diet reduces short-chain fatty acids synthesis and leads to the production of potentially harmful metabolites. Low fiber content in diets leads to the colon mucosa biological barrier destruction, causes inflammatory processes.

Functional food ingredients are actively used in molecular gastronomy for creating healthy food products include a number of components with different functional and technological properties, including such polysaccharides as inulin, fructooligosaccharides, lactulose, isomaltooligosaccharides, soy oligosaccharides, transgalactooligosaccharides, xylooligosaccharides, polydextrose etc. [23].

A.M.Ugolev is the author of the adequate nutrition theory. He had found that dietary fibers play a significant role in the normalization of the gastrointestinal tract, especially in the small and large intestine: they increase the muscle layer mass, affect its motor activity, the level of food substance absorbtion in the small intestine, pressure in the cavity of the digestive apparatus, electrolyte metabolism in the organism etc. [5]. There was found ability of dietary fibers, including polysaccharides and lignin, have to bind water and bile acids, as well as to adsorb toxic compounds. The ability to bind water has a significant effect on the transit rate of the gastrointestinal tract content. For example, the grain bran dietary fibers bind 5 times more water than their own weight, carrot and turnip fiber and pectin substances - 30 times more times more water than their own weight.

Also to gut microbiome biodiversity maintaining and immune system strengthening, it`s necessary to eat regularly food enriched with useful probiotics, metabiotics, fermented milk products, fermented vegetables, soaked berries and fruits. Definitions of microorganism groups, microbe products and their metabolites are presented in the Table 1.

Table 1. Concepts of probiotics, prebiotics, synbiotics, metabiotics.

Concept	Definition
Probiotics	Probiotics help restore the natural balance of bacteria in your gut (including stomach and intestines) when it's been disrupted by an illness or treatment
Prebiotics	A selectively fermented ingredient that results in specific changes in the composition and/or activity of the gastrointestinal microbiota, thus conferring benefit(s) on the host health
Synbiotics	Products that contain both probiotics and prebiotics, with conferred health benefits
Metabiotics	Metabiotics are the structural components of probiotic microorganisms, their metabolites, signaling molecules with a determined chemical structure

Probiotics are live microorganisms that confer a health benefit on the host when administered in adequate amounts [24].

Species of Lactobacillus and Bifidobacterium are most commonly used as probiotics, but the yeast Saccharomyces boulardii and some E. coli and Bacillus species are also used. Newcomers include also Clostridium butyricum, recently approved as a novel food in European Union. Lactic acid bacteria, including Lactobacillus species, which have been used for preservation of food by fermentation for thousands of years, can act as agents for food fermentation and, in addition, potentially impart health benefits. Strictly speaking, however, the term “probiotic” should be reserved for live microbes that have been shown in controlled human studies to impart a health benefit.

The prebiotic concept is a more recent one than probiotics and was first proposed by Gibson and Roberfroid in 1995 [26]. Key aspects of a prebiotic are that it is not digestible by the host and that it leads to health benefits for the individual through a positive influence on native beneficial microbes. The administration or use of prebiotics or probiotics is intended to influence the gut environment, which is dominated by trillions of commensal microbes, for the benefit of human health. Both probiotics and prebiotics have been shown to have beneficial effects that extend beyond the gut, but this guideline will focus on gut effects. Prebiotics are dietary substances (mostly consisting of nonstarch polysaccharides and oligosaccharides). Most prebiotics are used as food ingredients—in biscuits, cereals, chocolate, spreads, and dairy products.

Commonly known prebiotics are:

- Oligofructose
- Inulin
- Galacto-oligosaccharides
- Lactulose
- Breast milk oligosaccharides

Lactulose is a synthetic disaccharide used as a drug for the treatment of constipation and hepatic encephalopathy. The prebiotic oligofructose is found naturally in many foods, such as wheat, onions, bananas, honey, garlic, and leeks. Oligofructose can also be isolated from chicory root or synthesized enzymatically from sucrose.

Synbiotics are appropriate combinations of prebiotics and probiotics. A synbiotic product exerts both a prebiotic and probiotic effect.

Metabiotics are the structural components of probiotic microorganisms, their metabolites, signaling molecules with a determined chemical structure [27]. They can optimize host-specific physiological functions, regulator, metabolic or behavior reactions connected with the activity of host indigenous microbiota. Metabiotics have some advantages because of their exact chemical structure, very safe, well dosed and long shelf-life.

Examples of bacterial taxa that have been shown to affect immune homeostasis include bacteroides, bifidobacterium, clostridia, segmented filamentous bacteria and lactobacilli (Fig. 2).

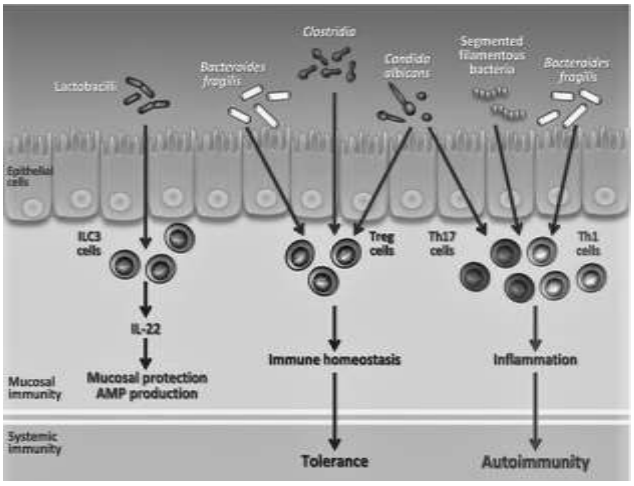

Fig. 2. Mechanism of bacteria metabolite action, by L.Romani et al. [28].

Data on the effect of metabolic products released by gut microorganisms is presented in the Table 2 [23, 24, 29].

Table 2. Effect of metabiotics produced by the gut microbiome.

Probiotics	Metabolite effect of the gut microbiome
Parabacteroides distasonic	Has antitumor activity
Bacteroidetes	Produces propionate
Lactococcus lactis subsp. lactis 194	Synthesizes antifungal substances and bacteriocins that suppress gram-positive and gram-negative bacteria and bacteriophages
Clostridium saccharogumia Eggerthella lenta Blautia coccoides Lactonifactor longoviformis	Promotes the isoflavone conversion into bioactive metabolites that reduce the cancer risk
Lactobacillus rhamnosus	Produces bacteriocins, reduces the infectious load on the organism when exposed to allergens, inhibits carcinogenesis, strengthenes the immune system
Lactobacillus hilgardii	Produces bacteriocins, cleanses the gut of harmfull metabolic products, helps to reduce human body weight by splitting lipids, strengthens the immune system
Lactobacillus acidophilus	Synthesizes the enzyme lactase, stimulates the dairy product digestion, promotes the vitamin K absorption
Bacillus subtilis	Produces butyrate and alpha interferon, strengthens the immune system, activates macrophages, and stimulates lymphocyte proliferation. Increases the activity of T and B lymphocytes. Increases the barrier function of the gut mucosa. Produces more than 100 bactericidal substances
Bacillus coagulans	Supports the necessary balance of gut microflora, stimulates the immune system
Clostridium butyricum TO-A Enterococcus faecium T-110 Firmicutes prausnitzii Roseburia hominis	Butyrate superproducers
Akkermansia muciniphila	Supports the gut microbiota in a healthy state
Alistipes indictintus Pontibacter lucknowensis	Reduces the level of bad cholesterol in blood. Promotes the insulin production
Faecalibacterium prausnitzii Bacteroides fragilis	Promotes the visceral fat breakdown, reduces fat mass and body weight
Oscillospira	Improves metabolism and reduces body weight
Faecalibacterium prausnitzii	Has powerful anti-inflammatory properties
Corpococcus Dialester	Participates in the neurotransmitter synthesis. The absence of these bacteria in the microbiome leads to development of depression

Recently scientists [30] have shown that one of the ways to reduce the obesity degree is the development of anti-obesity functional foods with gut microbiota-regulating activity. There are data in the literature of many animal studies confirmed some gut microbiota regulated by functional foods could decrease weight, while other gut microbiota regulated by functional foods could increase weight. This could be associated with the differences in gut microbiota, animal species, dosage, and duration. Furthermore, it is very difficult to transfer the results of animal studies into human beings because of the differences of gut microbiota in animals and human as well as over-high dosages used in animal studies, which are sometimes unrealistic in human. Therefore, a large number of studies are required for human in order to find differences or consistent effects before anti-obesity functional foods targeting gut microbiota can be developed [31, 32, 33].

4 Conclusions

One of the most promising areas of the food industry development is the convergence of nutrition science, molecular gastronomy, food engineering and innovative production practices. Modern advances in food biotechnology allow us to obtain symbiotic culture consortia to create healthy food products. Enrichment of food products with probiotics, metabiotics, polysaccharides and biologically active micronutrients will help to improve health, strengthen the human immune system and active longevity.

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