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FERMENTED VEGAN FOODS

S u m m a r y

In recent years, an increase has been reported in consumer awareness of balanced diet and health prevention. This caused the consumer interest in functional foods to increase. The major functional foods are products that contain prebiotics and probiotics. The most often eaten probiotic product is classic yogurt, however the fermented dairy and non-dairy drinks tend to be more and more important. The increase in number and types of milk-free drinks on the market is due to increasing lactose intolerance among consumers. Additionally, in the developed countries gradually rises the number of people who are switching to veganism. The search for suitable substitutes for dairy milk and dairy products has become an important direction of scientific research and implementation projects in industry. The objective of the paper is to review the reference literature presenting results of research studies and experiments on the production and qualities of non-dairy probiotic products, that could be classified into vegan foods. New probiotic food in the form of drinks, which are already on the market or are still in research phase, are made of raw materials such as: vegetables, fruits, grains (oats, buckwheat, spelt wheat, corn, quinoa, amaranth), hazelnuts, coconuts, almonds, cashew nuts, and also sesame and hemp seeds. It is a big challenge for technologists to manufacture food products for vegans, because the vegan diet is more restrictive than a vegetarian one, therefore possibilities of using many raw materials are limited.

Key words: veganism, fermented foods, probiotics, prebiotics

Introduction

In recent years, an increase has been reported in consumer awareness of food-related problems. The boosted awareness resulted in the increased interest in functional foods. The functional food market develops globally and is one of the most fascinating areas of research and innovation in the food sector, which is related with the growing number of scientific papers in the reference literature on this subject [8, 23, 33, 34, 50].

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One branch of functional foods includes fermented dairy drinks and yogurts. Those fermented beverages contain health-beneficial probiotics consisting mainly of the *Lactobacillus* and *Bifidobacterium* strains. Those probiotic strains, when supplied in adequate proportions, improve the balance of gastrointestinal microbiota of the host. It is believed that a low fibre intake, which can upset the microbiota of the human gastrointestinal tract, is one of the causes of the increasing number of chronic diseases in humans, for example cardiovascular disease, obesity or colon cancer. It raises the risk of gastrointestinal disorders, fungal colonization and inflammatory gut disease. Lifestyle, antibiotics, stress levels, invasive medical procedures and most of all, the type of diet are all said to have a significant impact on the state of gastrointestinal microbiota [15]. Probiotic products should contain a minimum daily dose of microorganisms [37], that is a required dose so as to guarantee specific health benefits i.e. boosting the immune system, increasing the bioavailability of nutrients, reducing the symptoms of lactose intolerance, suppressing the growth of pathogenic bacteria, decreasing the number of toxins produced by said bacteria and reducing the risk of certain types of cancer by, for example, indicating carcinogenic properties in chemoprevention of the large intestine [32]. Prebiotics are carbohydrates that occur naturally in food that are not digested in the small intestine and reach the large intestine in their original form [23]. The definition of prebiotics overlaps, to a certain extent, with the definition of fibre. The difference between the two definitions comes down to that the prebiotics display selectivity only towards certain bacterial strains, especially Bifidobacteria and lactic acid bacteria (LAB) [30, 52]. The following are the prebiotics usually used in human diet: lactulose, galactooligosaccharides, fructooligosaccharides, inulin (and its hydrolysates) and malto-oligosaccharides. They can all be found in various vegetables and fruits such as chicory, onion, garlic, asparagus, artichoke, leek, banana, tomatoes and many others [41, 42]. In addition to the health benefits, prebiotics possess significant technological advantages, such as the ability to improve the quality of taste and consistency, and emulsion stability. By combining probiotics and prebiotics in food products, a group of functional products is produced, which are referred to as synbiotics [24, 30]. The consumption of products containing synbiotics can balance the gut microbiota by raising the levels of Bifidobacteria [4, 24, 30]. Probiotics and prebiotics are applied more and more frequently as additives in non-dairy products [25].

The objective of the paper is to review the reference literature on the subject of milk-free probiotic products, which may serve as alternative foods for vegans.

Veganism

Veganism is becoming an increasingly popular modern-day lifestyle trend [26, 29]. It is an extreme variation of vegetarianism, because it advises abstaining from consuming and using all the animal products. Other types of the vegetarian diet are

more or less restricted and tolerate the consumption of the following: dairy products (lacto-vegetarians), eggs (ovo-vegetarians), dairy products and eggs (ovo-lacto vegetarians), only raw fruits and vegetables (raw foods diet), only fruits and vegetables the consumption of which do not cause the death of the plant (fruitarianism), raw foods in the form of a liquid (liquidarianism), only sprouts and seeds (sproutarian diet) [10, 29]. Researchers point out various reasons for adopting a vegan lifestyle. Among them, there are ethical and moral motives, reasons related to health benefits, feeling distaste towards meat products or being influenced by a friend group. When conducting their survey, Janssen et al. [17] noticed that many consumers, who chose to follow a vegan diet, based their choices on more than one reason. Dyett et al. [11] examined whether vegans, whose choice was driven by health-related reasons, practiced other forms of health-promoting activities and whether they showed more positive health results compared to those who chose veganism based on the motives other than health. Based on the analysis of the survey conducted in USA (n = 100), it was found that there was no significant difference between health behaviours of vegans, whose choice of lifestyle was dictated by different motive categories.

So far, the results of the research on health condition and nutrition of vegans determined that vegans had an average body mass index (BMI), lower levels of cholesterol and blood pressure. Also, they faced a lower risk of developing cardiovascular diseases and diabetes. Moreover, the vegan diet can reduce the risk of certain types of cancer to develop [24, 28]. However people who strictly follow vegan and vegetarian diets are more prone to a vitamin B12 deficiency [20, 51]. Such a deficiency is higher in vegans than in vegetarians. Cyanocobalamin (B12) occurs mainly in meat, shellfish, eggs, milk and other dairy products. That is why vegans and vegetarians strive to supply the body with the said vitamin through consuming special food products rich in vitamin B12 [20, 51]. Foods of plant origin do not contain vitamin B12 (except algae), but they can be fortified with it as in the case of some breakfast cereals. Vitamin B12 is responsible for producing erythrocytes and supporting the proper functioning of the central nervous system. Its deficiency can cause cardiovascular disorders, cerebrovascular disorders and macrocytic anemia. Despite the deficiencies and complications many vegans believe that the additional supplementation of cyanocobalamin is not required, because it occurs only after a long time when the reserves of vitamin B12 stored in the liver run out [9]. Siebert et al. [44] studied the impact of using a B12-fortified toothpaste on the status of B12 in vegans. The test was conducted on a group of vegans who used this toothpaste over a period of 12 months. Each of the participants was diagnosed with a vitamin B12 deficiency before the start of the study. The levels of vitamin B12 were checked before and after the period of using the toothpaste; the latter caused the vitamin B12 markers in the blood of vegans to be corrected.

Many vegans include the philosophy of following the diet into other areas of their life and treat it as a lifestyle with defined ethical, spiritual and environmental standards. Since the beginning of the 21st century the availability of vegan foods has much improved in the shops and supermarkets in many countries; this is related to the significant increase in the number of vegans in that period. Even though the percentage of people following a vegan diet constitutes only a fraction of the world population, it can be assumed that their influence on food industry will continue to grow [11, 17, 48]. It opens up a lot of opportunities for food producers who, by introducing new and innovative products, want to satisfy the needs of consumers even if the industry is not yet prepared to satisfy the needs of the vegan food market. Therefore, the vegans themselves fill the gaps by preparing at home the products not available on the market or by buying artisanal products that do not undergo strict control in terms of hygiene [43]. The most evident products the vegan diet lacks are dairy products. Their absence makes the vegan diet highly different from the vegetarian diet. The search for fitting replacements for milk and dairy products has recently resulted in conducting many studies into a wide variety of products in order to determine whether or not they could serve as fitting substrates in the production of new non-dairy products. Those new non-dairy products in the form of drinks contain probiotic strains derived from vegetables, fruits and grains (such as oats, buckwheat, spelt wheat, corn, quinoa or amaranth). The drinks made from soy were always used to replace cows' milk, but currently a wider range of plant-based products is applied. Many products are produced using hazelnuts, coconuts, almonds, cashew nuts, sesame and hemp seeds. Such drinks are available in many varieties: sweetened, unsweetened, ecological and enriched. They provide various ingredients and support disease prevention. The drinks are also available in a variety of tastes [22, 23]. The drinks are produced with the use of selected lactic bacteria, mainly the strains with proven sensory features. Their fermentation takes place under the controlled conditions. Owing to various organic acids produced, they inhibit the growth of undesirable bacteria, thereby preserving the food. Moreover, the resulting products have specific tastes and aromas [36, 37]. The utilization of those drinks is often restricted because of the sensitivity of their ingredients, the concerns about contamination and the low storage viability of strains. Currently there are carried out research to resolve those issues [37].

Cereals

Many non-alcoholic drinks made from fermented cereals are produced worldwide (Tab. 1). Those drinks are associated with various traditions and preferences that differ based on the region of their origin [40]. Some of the probiotic drinks were developed using germinated and non-germinated seeds of barley, finger millet and moth bean [1, 6, 40]. Made from fermented cereals, kvass is a non-alcoholic beverage found in some

regions of the eastern European countries (Poland, Latvia, Russia and Ukraine) [13, 21].

The results of fermentation, carried out with the above specified cereals and culture combinations, could provide more information on the compounds, which are most important for the final consumer acceptance (taking into account such indicators as taste, colour, clarity and intensity of sweet taste) of cereal beverages, and on how those components could be enhanced with the use of different technological conditions and starter cultures [12, 49]. More popular ancient or ethnic grains pose a big challenge for food technologists in terms of fermentation, because they need to merge appropriate technologies and sensory properties with nutritional benefits [7, 34].

Table 1. Examples of non-alcoholic drinks made from fermented cereal products
Tabela 1. Przykłady napojów bezalkoholowych wyprodukowanych z fermentowanych surowców zbożowych

Name Nazwa	Seeds of cereal or pseudo-cereal Nasiona zboża lub pseudozboża	Country or region of origin Kraj lub region pochodzenia	References Literatura
Boza	wheat, millet, rye, corn pszenica, proso, żyto, kukurydza	Albania, Bulgaria, Turkey, Romania Albania, Bułgaria, Turcja, Rumunia	[1, 14, 44]
Bushera	millet, sorghum / proso, sorgo	Uganda	[6, 12]
Mahewu	corn / kukurydza	Africa / Afryka	[6, 12]
Pozol	corn / kukurydza	Mexico / Meksyk	[6, 12]
Chyang (kodo ko jaanr)	barley or finger millet (ragi) jęczmień albo manneczka łękowata	North-eastern India Północno-wschodnie Indie	[13, 41]
Kunu-zaki and pito / Kunu-zaki i pito	barley, finger millet, moth bean (*Vigna aconitifolia*) / jęczmień, manneczka łękowata, fasola matowa (*Vigna aconitifolia*)	Nigeria	[12]
Kvass Kwas chlebowy	fermented cereals fermentowane zboża	Poland, Latvia, Russia, Ukraine Polska, Łotwa, Rosja, Ukraina	[13, 21]

Vegetables

Special attention should be given not only to the natural nutrients in food and their positive effect on health, but also to the phytochemicals in vegetables. More and more attention is given to the pro-health and dietary properties of soured vegetables. They contain carbohydrates and therefore they are suitable substrates and can be used to carry out lactic acid fermentation. Fruits and vegetables are known to be perishable goods because of their high water activity. Therefore fermentation is one of the methods to preserve them. Fermented vegetable juices can be produced by the natural plant fermentation, i.e. by squeezing out juices as in the case of sauerkraut or by fermenting

the juice. The juice fermentation can be either a spontaneous process activated by natural microflora, a process launched by starter cultures added to raw materials or a process where raw materials undergo heat-treatment and ferment with the use of starter cultures. The soured products produced using those fermentation processes have low calorific value, contain fibre, vitamin C, B-group vitamins and antioxidants. Their nutritional value improves during the fermentation process [35, 45]. Chinese cabbage, cabbage, tomatoes, carrots and spinach have higher fermentability for they contain fermentable saccharides. The fermented vegetable juices are most often produced using red beets, carrots, celery and tomatoes. Turnips, radishes, sweet potatoes, olives, peppers, peas, horseradish and cauliflowers are also used for pickling. Rakin et al. [38] fermented beetroot and carrot juice with the added yeast autolysis. After the completion of the process, the juice had an optimal proportion of pigments, vitamins and minerals compared to the beetroot or carrot juice. Yoon et al. [57] fermented cabbage juice and concluded that *Lactobacillus plantarum* and *L. delbrueckii* were those lactic acid bacteria that should be used to carry out such a process. Traditional Korean kimchi is an interesting fermented product. It consists of fermented vegetables, mainly the Korean cabbage, radish with garlic, red pepper and green onion [31]. It has a sweet and sour flavour, which makes it different from the sauerkraut or pickled cucumbers that are popular in the West. To achieve such a taste, the process of fermentation should be carried out at lower temperatures to avoid the development of a strong acid [18, 19].

Soy

Soy is the most popular product used as a milk replacement; owing to its characteristics, it has an enormous potential in the food industry [54]. Other popular soy foods are miso, natto and tempeh [53, 54]. Owing to its properties, it helps prevent the risk of certain heart diseases, osteoporosis and kidney diseases [5, 54]. The fermentation of soy drinks increases the bioavailability of isoflavones, improves digestion of protein, supports the immune system and promotes gut health**.** Soy isoflavones (daidzein, genistein and glycitein) are the focus of recent interest in the nutritional benefits, because those phytoestrogens occur in relatively high concentrations in soy products [5, 56]. However, the application of isoflavones is still controversial because of their anti-estrogenic properties [56].

What is more, oligosaccharides found in the soy milk cause flatulence and the fermentation of soy drinks makes them easier to digest. The lactic acid bacteria-based fermentation makes it possible to produce products showing better consumer acceptability, such as soy cheese, soy yogurt or fermented soy milk drinks. The distinctive taste of soy milk can be masked by adding sugar, aromas, fruit pastes and juices. The fermented soy drinks and yogurts can be additionally enriched with inulin and oligofructose. In order to improve the acceptability of the final product, Içier et al. [16] at-

tempted to prepare – using *Lactobacillus acidophilus* – a soy drink with apple juice added. According to the results, the addition of apple juice (at concentration rates of 15 %, 25 %) had no significant effect on the growth of *L. acidophilus*. However, the panellists preferred the fermented soy milk beverages with 25 % of apple juice added (in terms of the following parameters: colour, consistency, acidity, apple flavour). It turned out their product was sensory acceptable and guaranteed microbiological stability.

Fruits

Lately, researchers have been interested in fruit drinks with probiotic and prebiotic substances added. Fruit juices contain beneficial nutrients such as vitamins, fibre, antioxidants and minerals. In addition, they do not contain dairy allergens. They are regarded to be healthy, refreshing and possessing a pleasant flavour profile, which makes them a perfect raw material for use in the production of fermented drinks [35, 45, 47]. An example of a fruity probiotic drink is hardaliye, a Turkish product made from naturally fermented red grapes [1, 2]. In their study, Luckow et al. [22] compared the consumer acceptance of the appearance, aroma, texture and flavour of fermented blackcurrant juice (containing *Lactobacillus plantarum* 299v cultures) with the conventional juice (n = 425). It was determined that females over 40 and the older consumers significantly preferred the sensory qualities of the probiotic juice. What's more, they declared to be willing to drink probiotic juices a few times a week. Also, those authors carried out a research study on the effect of functional ingredients on the aromas and flavours of orange juices. In this case, the results of the research indicated that the consumers preferred the conventional juices.

The most popular fruits that are grown in the temperate zone are: cherries, pears and peaches [33, 42]. Seasonal, tropical fruits are also well-liked, for example watermelons, pomegranates, unripe mangoes, lemons, bananas, papayas and pineapples. From the economical point of view, jackfruit, sapota, jamun, fendu and the cashew are most important. The tropical fermented juices are characterised by their nutraceutical potential when treating fever, cold, diabetes and skin conditions. Their strong antioxidative properties make them suitable for use in both the pharmaceutical and the food industry [33]. The issues one can come across when producing fermented fruit juices are associated with the limited viability of probiotics. The following parameters impact probiotics: pH, water activity, occurrence of sugar, salt, artificial aromas, food dyes and preservatives. There are two main criteria that have to be met – the content of probiotics (at least 106 - 107 cells/ml) has to be maintained as has the activity of probiotics in food products at the end of their shelf life. Important are also the following processing parameters: extent of heat treatment, incubation temperature, packaging materials and storage. Of all the parameters listed, pH is one of the most important

parameters, because fruit juices have naturally high levels of organic acids. The easiest way to improve the probiotic stability in fruit juices is to fortify them with prebiotics, for instance with a dietary fibre [39].

Nuts and chestnuts

Researchers start to get interested in the products made from fermented nuts; so far there is still not much information about those processes [37]. In this category the main products are those made from cashews, almonds, macadamia nuts and other nuts. The nuts are soaked, minced with the water they were soaked in, and fermented using the spontaneous fermentation process. Tabanelli et al. [46] attempted to produce products made from cashew nuts; then, their products were used in the pilot study. The contents of essential fatty acids in them made it nutritionally and commercially valuable. However, further research is necessary on how to shorten the time of fermentation.

Chestnuts are another product studied by researchers. This raw material is low in fat and high in carbohydrates. Chestnuts are a great source of vitamins C, E, B1, B2, B3, pantothenic acid, folic acid, as well as important microelements and macroelements [27]. They contain gallic and ellagic acids and have antioxidant, anti-inflammatory and anticancerogenic properties. Chestnuts are consumed mainly in the form of fresh fruit; on the market they can also be found in the more processed form, for example jams. Fruits that do not meet higher quality requirements (e.g. broken or dry chestnuts) are used to produce flour, non-alcoholic drinks or as animal feed [3, 27, 39]. In order to search for alternative foods, Blaiotta et al. [3] examined the usefulness of dried chestnuts for the production of lactose-free and low-fat beverages. The idea was to prepare chestnut purees fermented by selected lactic acid bacteria strains. The *in vitro* tests performed proved the probiotic potential of selected *Lactobacillus rhamnosus* and *L. casei* strains. The research conducted confirmed the possibility of preparing chestnut purees. It is possible to state that a new concept of food has been created, where the nutritional qualities of chestnuts were combined with the human health benefits of lactic acid bacteria strains [3].

Irritable bowel syndrome

Fermentation processes are important not only because of the probiotics found in the fermented products, but also because fermentation is one of the methods to reduce the amount of fermentable short-chain carbohydrates [49, 55]. A lot of fermentable short-chain carbohydrates can be found in a vegan diet. In the long run vegetarian diet can cause irritable bowel syndrome characterised by persistent gastrointestinal symptoms, for example flatulence. It is a challenge for vegans how to combine the pure plant-based diet with the one with no fermentable short-chain carbohydrates. To treat the above mentioned diseases, the FODMAP (oligosaccharides, disaccharides, mono-

saccharides and polyols) diet is advised [53]. Under the low FODMAP diet it is recommended to reduce the consumption of legumes, nuts, seeds and soy-based products, i.e. the most frequently consumed food products by vegans [26]. To date, all of the usual vegetables, fruits, grains and nuts have been examined [49]. Based on the research results, it was found that of the products consumed by vegans, a low FODMAP level have canned coconut milk, nutritional yeast, soy cheese, tempeh, vegan yolk, egg replacement and spirulina. In addition to fermentation, the following methods can reduce the content of FODMAP: soaking, boiling, sprouting, enzymatic treatment, extraction using ethanol, genetic manipulation and dehydration. Boiling seems to be an effective method for the oligosaccharides that are water-soluble. The oligosaccharides that remain in water are removed with it. Pickling and preserving are food processing techniques to cause the highest reduction of fermentable short-chain carbohydrates [49].

Conclusions

The vegan diet is more restrictive than the vegetarian diet. There are sought products to diversify the vegan diet. These include dairy-free probiotic products. Many consumers might support new products provided they know such products are beneficial for both the human health and the environment. However, it must be mentioned that the nutritional, not the environmental, information had a stronger effect on how the participants appreciated the product and whether or not they were willing to purchase it.

The application of the mixed-culture fermentation is very important in regards to improving the sensory qualities and nutritional value of plant-based materials. The creation of mixed cultures depends both on the species and strains. Currently, the strain combination is still made with a trial and error approach. The knowledge of microbial interactions is insufficient, thus it is difficult, if not impossible, to predict the results of mixed cultures. To develop desired fermentation processes and finally products of higher quality, it would be of great help to find methods of choosing a more rational selection and combination of strains, so that predictable synergistic reactions might happen.

The variety of flavours and health benefits of vegan products cause the vegetable fermentation to gradually become more and more common. However the lack of information on the microbiological process is cause for concern about the food safety. The food industry makes a great effort to respond to this expanding market although the food safety of some plant-based products has not been well established.

The fermented products, e.g. nut and grains milk, fruits and vegetables, may be a source of biogenic amines. However, the levels of such compounds should be taken into consideration before including such products into a daily diet.

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FERMENTOWANA ŻYWNOŚĆ WEGAŃSKA

S t r e s z c z e n i e

W ciągu ostatnich lat zaobserwowano wzrost świadomości konsumentów w zakresie zbilansowanego żywienia oraz profilaktyki zdrowotnej. Spowodowało to wzrost zainteresowania konsumentów żywnością funkcjonalną. Podstawowym rodzajem żywności funkcjonalnej są produkty zawierające szczepy probiotyczne i prebiotyki. Najczęściej spożywanym produktem probiotycznym jest klasyczny jogurt, ale coraz większego znaczenia nabierają fermentowane napoje mleczne i bezmleczne. Wzrost liczby i rodzajów napojów bezmlecznych na rynku spowodowany jest coraz częściej występującą nietolerancją laktozy wśród konsumentów. Ponadto w krajach rozwiniętych sukcesywnie zwiększa się liczba osób przechodzących na weganizm. Poszukiwanie odpowiednich zamienników mleka i przetworów mlecznych stało się ważnym kierunkiem badań naukowych i prac wdrożeniowych w przemyśle. Celem opracowania jest przegląd literatury dotyczący wyników badań i prac eksperymentalnych związanych z wytwarzaniem i właściwościami niemlecznych produktów probiotycznych, które można zakwalifikować do żywności wegańskiej. Nowa probiotyczna żywność w postaci napojów, jakie znajdują się już na rynku lub są jeszcze w fazie badań, produkowana jest z surowców takich, jak: warzywa, owoce, nasiona zbóż (owsa, gryki, orkiszu, kukurydzy, komosy ryżowej, amarantusa), orzechy laskowe, kokosy, migdały, orzechy nerkowca, a także nasiona sezamu i konopi. Produkcja wyrobów dla wegan jest dużym wyzwaniem dla technologów, ponieważ dieta wegańska jest bardziej restrykcyjna od wegetariańskiej, stąd możliwości wykorzystania wielu surowców są ograniczone.

Słowa kluczowe: weganizm, żywność fermentowana, probiotyki, prebiotyki