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POSSIBILITIES OF OBTAINING AND VALORIZING DIETARY FIBERS IN THE CONTEXT OF THE CIRCULAR BIOECONOMY

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Abstract. This article aimed to review the recent literature on the characterization of dietary fibers and their role in the human body, focusing on the methods of extraction of dietary fibers from agro-food waste as well as their use in various areas of the food industry. Dietary fibers are biologically active substances with beneficial effects on human health. Soluble dietary fiber is involved in reducing cholesterol levels and blood sugar levels, while insoluble dietary fiber helps regulate intestinal transit and maintain colon health. It would be useful to identify the extraction procedures and characterization of dietary fibers from agro-food waste. Fruit waste contains relevant amounts of bioactive compounds, such as: phenolic acids, flavonoids, lignins, carotenoids, etc. In addition, fruit waste contains significant amounts of dietary fiber with nutraceutical important activities, such as modulating the intestinal microbiota, lowering cholesterol, triglycerides and glycemic load in the blood. Hence, obtaining dietary fiber from agro-industrial waste can solve a number of economic and environmental problems that aim reducing waste, increasing the sustainability and profitability of companies in the Republic of Moldova. Dietary fiber can be used in various types of food, such as products of bakery and confectionery, meat, dairy products, and pasta. They can be used as stabilizers with an impact on food texture or ingredients with low caloric value, partially replacing caloric constituents such as fats, starch or sugars. Another important property is the prebiotic effect of dietary fibers. This property is determined by the fact that dietary fibers are indigestible or poorly digestible and are fermented selectively by intestinal microbiota, conferring health benefits to the host.

Keywords: *agro-food waste, dietary fiber, extraction methods, physiological effects, functional products.*

Rezumat. Acest articol și-a propus să revizuiască literatura recentă despre caracterizarea fibrelor alimentare și rolul lor în organismul uman, cu accent pe metodele de extracție a fibrelor alimentare din deșeuri agroindustriale precum și utilizarea lor în diverse domenii ale industriei alimentare. Fibrele alimentare sunt substanțe biologic active cu efecte benefice asupra sănătății umane. Fibrele alimentare solubile sunt implicate în reducerea nivelului de colesterol și a glicemiei, în timp ce fibre alimentare insolubile ajută la reglarea tranzitului intestinal și la menținerea sănătății colonului. Prezintă interes identificarea procedeelor de extracție și caracterizare a fibrelor alimentare din deșeuri agroalimentare. Deșeurile din fructe conțin cantități relevante de compuși bioactivi, cum ar fi: acizi fenolici, flavonoide, lignine, carotenoide etc. În plus, deșeurile de fructe conțin cantități semnificative de fibre alimentare cu activități nutraceutice importante, cum ar fi modularea microbiotei intestinale, scăderea colesterolului, trigliceridelor și încărcăturii glicemice în sânge. Prin urmare, obținerea fibrelor alimentare din deșeuri agroindustriale poate rezolva o serie de probleme economice și de mediu care au drept scop reducerea deșeurilor, sporirea sustenabilității și profitabilitabilității întreprinderilor din Republica Moldova. Fibrele alimentare pot fi utilizate în diverse formulări alimentare, cum ar fi produse de panificație și de cofetărie, carne, produse lactate, și paste făinoase. Acestea pot fi utilizate ca stabilizatori cu impact asupra texturii alimentelor sau ingrediente cu valoare calorică scăzută, înlocuind parțial constituenții calorici precum grăsimile, amidonul sau zaharurile. O altă proprietate importantă este caracterul prebiotic al fibrelor alimentare. Această proprietate este determinată de faptul că fibrele alimentare sunt nedigerabile sau slab digerabile și sunt fermentate selectiv de microbiota intestinală, conferind beneficii pentru sănătate gazdei.

Cuvinte cheie: *deșeuri agroalimentare, fibrelor alimentare, metode de extracție, efecte fiziologice, produse funcționale.*

1. Introduction

In recent years, there has been a particular interest in the development of functional foods mainly because they can provide physiological and nutritional benefits. These foods contain bioactive compounds including dietary fiber [1]. The health-promoting potential of dietary fiber includes lowering blood cholesterol and sugar levels, improving cardiovascular health, and more [2]. The recommended daily intake of dietary fiber is 38 g/day for men and 25 g/day for women, while the actual average intake is only 15 g/day [3]. In addition, dietary fiber is a promising food additive with technological properties necessary for the development of value-added products that promote health [4]. To meet dietary fiber requirements, the food industry is concerned with identifying low-cost dietary fiber sources with improved functional properties that allow obtaining food products with unique characteristics. In this context, fruit and vegetable by-products seem to be a promising alternative. In addition, the use of these by-products contributes to the reduction of residues and waste, which is a serious environmental problem worldwide [5].

The term "dietary fiber" was first mentioned in 1953 by the British scientist Eben Hipsley, who defined it as a component of the cell wall of plants that is not digested by the human body [6]. Subsequently, the concept of "dietary fiber" underwent a number of modifications and additions as additional analyses and observations concerning this group of components began to be carried out. Thus, according to the generally accepted explanation formulated in Codex Alimentarius Alinorm in 2009, digestible fiber is a group of substances, polysaccharides with three or a bit more monomers, which are unaffected by the action of digestive enzymes of endogenous nature, which implies that they cannot be broken down and assimilated by the small intestine [7]. However, it should be noted that the group of dietary fiber also includes lignin, which is a non-carbohydrate substance, a polymer contained together with cellulose in the cell membrane. On the basis of the sources of derivation, dietary fiber can be classified as follows: i) polysaccharides that are part of the chemical composition of the edible parts of fresh fruits, vegetables and cereals; ii) dietary carbohydrate polymers that can be obtained from the crude products by physical, enzymatic and chemical methods and have proven biophysiological benefits to the human body (e.g. inulin); iii) artificially derived (synthetic) polysaccharides, also with proven benefits (e.g. methylcellulose) [8].

It should be noted that today there is an increasing interest in zero-waste production, that is, the use of all possible parts of food raw materials in maximum quantities, which will reduce the number of wastes. This is due to the fact that the amount of waste generated in food production has increased over the years, hence the economic and environmental problems have increased [9]. In order to minimize these problems, it is necessary to take food waste into consideration in order to explore its further use in the food industry as well as other industries. Such wastes are usually valuable raw materials in terms of dietary fiber or bioactive components. Dietary fiber, especially pectin, are usually obtained from apple pomace, pears or plums, raw materials that are typical for the Republic of Moldova.

Edible fiber extracted from vegetable and fruits by-products of processing can be used for food fortification. Extraction of these components is carried out in order to develop and produce functional foods.

The EU food industry produces more than 100 million tonnes of waste consisting of inedible plant tissues (seeds, peels, husks, etc.) every year. Most of this waste can be utilized to produce food supplements of high nutritional value. The dietary fiber as well as other compounds such as essential oils, proteins, pigments and flavor compounds can be isolated using various extraction methods [10]. Therefore, this article aimed to review the recent literature on the characterization of dietary fibers and their role in the human body, focusing on the methods of extraction of dietary fibers from agro-food waste as well as their use in various areas of the food industry.

2. Characteristics of dietary fibers

Dietary fibers are carbohydrate polymers such as cellulose, hemicellulose, lignin, and pectin that provide structural rigidity to the plant cell wall. Based on water solubility, dietary fiber is classified as soluble dietary fiber and insoluble dietary fiber. Insoluble dietary fiber is resistant to the digestive enzymes of the human gastrointestinal tract and accounts for approximately 2/3 of the fiber volume in most foods. They include cellulose, hemicellulose, lignin, and resistant starch [6].

Cellulose is a polymer of natural origin, which is often obtained from plants, as it is the basic element of their cell wall. It equally be further synthesized and modified in laboratory conditions to improve the chemical and physical properties of the substance. Chemically, cellulose is an unbranched carbohydrate composed of multiple D-glucose monomers (more than a thousand units) [11].

Hemicellulose also like cellulose is a biopolymer that is predominant in the cell wall of wood and annual plants. Unlike cellulose, it belongs to the class of heteropolysaccharides, that is, it consists of various residues of simple sugars (in addition to glucose, it includes xylose, mannose, galactose, etc.) [12].

Lignin is a part of the cell barrier which allows hemicellulose and cellulose to bind together, which gives the cell a stiffer and more impermeable structure. Compared to the previous two fibers, lignin is not a carbohydrate but is a phenolic polymer [12].

Resistant starch is starch and other starch breakdown products that enter the body with food but cannot be digested by enzymes of the human digestive tract. Thus, resistant starch passes through the small bowel directly into the large intestine, after which it is excreted from the body or undergoes fermentation and as a consequence serves as a necessary carbon substrate for the vital activity of intestinal microflora. A special feature of this group is its specificity for each individual, i.e. it is not necessarily the case that the same type of starch for two different people will be resistant [13].

Soluble dietary fibers are dissolved in an aqueous enzymatic medium. They are characterized by the absorption of water with the formation of a gel, which in turn affects the digestive processes, slowing them down. This group is represented by pectin, beta-glucans (β-glucans), galactomannan gum and inulin [6].

Pectin is a natural polymer and structural component of plant cell wall, which is well soluble in water. This polysaccharide is able to retain water and form gels, which takes an active participatory stance in the alimentary sector [6].

β-glucans are polysaccharides consisting of several glucose molecules, capable of being produced by many prokaryotic and eukaryotic organisms. In addition, this group of sugars is found in the cell walls of bacteria, fungi, yeasts, algae, and cereal plants, especially oats and barley [14].

Galactomannan gums are natural polysaccharides usually extracted from the endosperm of various leguminous crops. The peculiarity of chemical structure is mannose chain with galactose branches, hence is a heteropolysaccharide. It also has antioxidant and antibacterial properties [15].

Inulin is a carbohydrate polymer that is a natural, water-soluble dietary fiber and is also found in many plants as a backup energy source. Inulin is chemically structured as a carbohydrate consisting of several fructose residues. In addition to its fiber properties, inulin serves as an effective prebiotic, providing the necessary conditions for the development of a favorable intestinal microflora in our body [16].

For each type of dietary fiber, there are certain raw materials in which it predominates and from where it can be extracted to improve the characteristics of the finished product. Thus, insoluble fiber is predominantly found in cereals and bran, fruits and vegetables, and legumes. In turn, soluble types of dietary fiber are common in a more diverse range of foods. For example, apples and citrus fruits are high in pectin and pectin substances, while β-glucans are prevalent in bran and cereal grains such as oats and barley. Galactomannans, on the other hand, can be found in legumes other than cereal grains. For inulin, the best-known sources are Jerusalem artichoke (*Helianthus tuberosus*) and chicory, and in smaller concentrations onion and garlic [17].

As mentioned above, dietary fiber can be obtained directly from the intake of vegetables and fruits, berries and cereals, or through the extraction of these substances during their technological processing, which is of great interest to the food industry. This allows combining several production problems: increasing the biological value of products and minimizing food waste at the end of the technological process. Especially for the Republic of Moldova with its diversity of agricultural products.

3. Dietary fiber from agro-food wastes

In this paper we will consider dietary fiber, which can be obtained directly from fruit crops or from the products of their processing, typical for our republic. It is conditioned by the fact that at this stage of food industry development it is necessary to improve production technologies at the expense of more rational use of vegetable raw materials and reduction of food waste in the process of their processing.

Referring to the statistical data, it is possible to determine the sown areas and annual yield of fruit species for the year 2022, which will clearly demonstrate the most developed areas of fruit and berry cultivation on the territory of the Republic of Moldova, Figure 1 [18]. As a result of the study of statistical data, it was revealed that the yield of apples for 2022 was 447.7 thousand tonnes, which was harvested from 51.2 thousand hectares of land. For pears and quince these figures were 4.7 and 2.6 thousand tonnes from 2.8 and 1.2 thousand hectares respectively. Peaches and apricots were grown on 5.4 thousand hectares for the former and 4.5 thousand hectares for the latter, accounting for 20.5 and 11.8 thousand tonnes of yield. Plum as well as apples occupy relatively large areas equal to 21.0 thousand hectares, and their quantitative indicator is 100.2 thousand tonnes of fruit [18].

If we consider berries, the biggest specific weight falls on grapes and makes 528.2 thousand tonnes of harvest, and the sown areas occupy 116.5 thousand hectares. These indicators exceed the values of any fruit grown on the territory of the Republic of Moldova in 2022 [18].

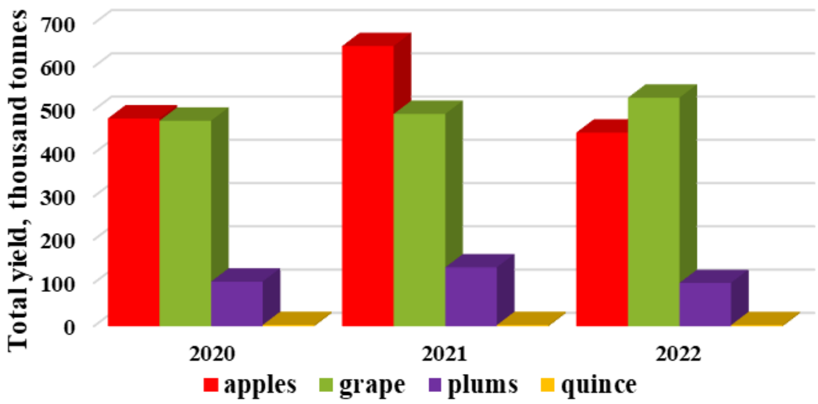

Figure 1. Yield volumes of some fruit and berry species in the Republic of Moldova (years 2020-2022) [18].

On this basis, it can be concluded that on the territory of Moldova the most common fruits are grapes, apples and plums and, therefore, it is appropriate to consider them as a nutritional fiber source for food fortification.

It can also be noted that quince is a specific fruit for this region, which makes it appropriate to study it as an additional source of fiber, despite the insignificant volumes of its cultivation.

3.1 Apple

Apple is a product of wide use, both fresh and in technological processes, due to its balanced and nutritious composition and variety of varieties. The biological value of the edible parts of apples can vary for each component based on the species, cultivation and degree of processing.

However, the main and characteristic components of each species are water, which occupies the largest percentage of the product (85.60 %), followed by sugars (13.8 %), proteins and lipids in smaller quantities, and dietary fiber, which is of interest to us, which amounts to about 2.40 g/100 g of product [19].

Among the micronutrients, we can mention that apple is a good source of potassium (107 mg/100 g), β-carotene (27 mg/100 g) and other minerals and vitamins such as phosphorus, calcium, magnesium, vitamin C and B group and others [19].

As mentioned earlier, apples are universally used in food processing technology in large quantities, and this, in turn, is accompanied by a significant amount of wastes from their processing. Mainly apple by-products include peel and pulp (95 %), seeds (2-4 %), and stems (1 %) [20], which exhibit high biological properties and have the potential to be reused as a great source of bioactive substances. The chemical composition of apple crop by-products is mainly represented by dietary fiber, phenolic compounds, and fatty acids and also, they include carbohydrates, proteins and ash to a lesser extent [21].

Dietary fiber accounts for 55.48 g/100 g dry matter (DM), of which the largest percentage is insoluble dietary fiber (43.58 g/100 g DM), the remaining 11.06 g/100 g DM reflects the quantitative content of soluble dietary fiber [22]. The quantitative and qualitative composition of dietary fiber varies from variety to variety, but this does not reduce the importance of using apple by-products for enrichment of mass-produced food products.

For example, in their study, a doctoral student from the Wroclaw University of Environment and Life Sciences demonstrated the quantitative content of insoluble dietary fiber in pomace from two apple varieties Aidared and Champion. The outcome of this research indicated that cellulose and hemicellulose were predominant in the Champion variety compared to the Aidared variety, and the amounts varied between 16.10g/100 g DM and 9.37g/100 g DM for Champion, respectively. Aidared is slightly inferior in quantitative values for cellulose (13.64 g/100 g DM) and to a large extent for hemicellulose (4.26 g/100 g DM). However, when studying lignin, a variation of values was found, i.e. an advantage was noted in the performance of the Aidared variety, and it varied between 6.17 g/100 g SM (Aidared) and 5.80 g/100 g DM (Campion) [23].

The most common soluble dietary fiber of apple fruits are pectin and pectin substances, which are already quite extensively applied in the food processing industry as a jelly component (mainly in the manufacture of confectionery products).

3.2 Grape

In addition to apples, the fruit of grapes is also rich in chemical composition and of high economic importance. This is due to the quantitative indicators of the harvested crop, as well as the products processed from it. For example, according to [18], the wine production in the Republic of Moldova in 2022 was 14.4 million decalitres. The result of the whole production is not only the finished product, but also the food waste that is not used further, such as pips, skins, pulp residues, etc., which has a significant impact on the economy of the enterprise and the ecology of the country.

However, it should be noted that the products of processing in wine production have high biological value, due to which they can be used as functional additives in the production of other types of products. These components contain high amounts of dietary fiber, both soluble and insoluble, as well as polyphenolic compounds, which can also be used to improve the performance of the final product.

Based on a study by the Complutense University of Madrid, white grape pomace contains 76.37 g/100 g DM of dietary fiber, of which 23.01g/100 g DM-soluble and 53.36

g/100 g DM-insoluble dietary fiber. Also, the amount of extractable phenolic compounds varies from 7.82 to 7.88 g/100 g DM. In supplementing the above components, grape pomace contains proteins, fats, carbohydrates, organic acids, and other substances [24].

3.3 Plum

The third object under study is plum fruits, which are also quite widespread within our country. Their quantitative indicators are comparatively lower than the two previous samples, but still make up a decent specific volume of the total amount of cultivated fruits and berries. On the chemical side, these fruits also have a high value and diversity of composition, which is similar to apples in terms of large amounts of water (86-89 %) and carbohydrates (6.7-15.0 %), proteins and fats make up a relatively small proportion (up to 1 %), and dietary fiber varies from 1.3 to 2.4 %. In addition to fiber, plum fruits contain phenolic compounds (111 mg/100 g), as well as trace elements represented by various minerals (potassium, calcium, magnesium, and others) and vitamins (mainly B vitamins) [25]. If we consider the dietary fiber included in plums, the main mass is represented by pectin as soluble dietary fiber, as well as lignin and cellulose as insoluble fiber. Their specific gravity is 0.76 g/100 g, 0.30 g/100 g and 0.23 g/100 g, appropriately [26].

3.4 Quince

The composition of quince fruits is quite diverse and balanced, which is interesting from a biological point of view due to the positive effects on the human body. Their consumption can help in the fight against asthma, liver disease, digestive disorders, heart disease, and also helps to improve immunity in general. Like all fruits contains a large amount of free moisture and soluble carbohydrates, a small amount of fats and proteins. The vitamin composition in quince is different and is represented by both water-soluble (group B and vitamin C) and life-giving vitamins (A, E, K) [27]. To mineral substances can be attributed potassium, phosphorus, calcium, magnesium, a little sodium, iron and zinc. In addition to the listed components of quince fruit, they also include organic acids, polyphenolic compounds, and also certain types of amino acids (aspartic acid, asparagine and glycine) [27]. The active ingredients in the fruit are the tannin in the seeds, but it should be noted that consuming the seeds in large quantities can be toxic. Other active ingredients include pectin, mucilage, sugars and organic acids found directly in the fruit. Dietary fibers also have their specific weight in this fruit and are present in both forms: soluble mainly in the form of pectin and insoluble - cellulose and lignin [27].

Thus, in the work of Romanian researchers, the quantitative content of cellulose, lignin, and the total amount of non-cellulosic polysaccharides (hemicelluloses) in quince pomace was determined based on the processing method. Three samples were submitted: untreated pomace and pomace treated with water or ethanol. The results ranged from 6.24 to 11.07 % for cellulose, 27.78 to 34.97 % for lignin, and 22.07 to 33.62 % for hemicelluloses. Describing each sample in more detail, the untreated pomace was characterized by a higher cellulose content (10.16 g/100 g), an average lignin content (30.10 g/100 g) and a relatively low amount of non-cellulosic polysaccharides (23.43 mg/100 g). The ethanol treated sample had the highest values for lignin (33.30 g/100 g) and hemicellulose (32.93 mg/100 g) and the lowest value for cellulose (6.80 g/100 g) among the presented pomace. In turn, water treated pomace had intermediate values for cellulose (9.55 g/100 g) and hemicellulose (25.56 mg/100 g) and the lowest value for lignin (28.70 g/100 g) [28].

In summary, it can be concluded that the selected raw material is a good source of dietary fiber not only in its natural appearance but likewise as processed products (fruit pomace). This observation allows us to set the direction for further studies in order to solve both economic and environmental problems of the country and physiological disorders in the population (reducing the risks of various diseases by enriching food products).

4. Extraction methods for dietary fiber

Currently, chemical, mechanical, thermal and/or enzymatic processing methods are used to extract dietary fiber or to enhance their extraction from plant materials. The yield and functional properties of the dietary fiber gained are predominantly dependent on the extraction conditions, which include temperature, processing duration, solvents, and pH [29]. Thus, the reviewed studies aim to optimize these conditions by applying classical methods together with modern methods to minimize the consumption of solvents and/or duration and temperature to achieve food products with at the target rate of output and quality parameters [30].

Such developments are contributing to a significant change in the industrial paradigm, calling for more sustainable methods as well as a more responsible approach to the environment. In parallel with the technological advantages, there is an emphasis on material and technical research that will reduce the environmental impact of obtaining raw materials, which in turn reduces the number of resources used and waste generated.

There has been a significant increase in interdisciplinary co-operation between engineering and science, addressing complex problems of efficiency, sustainability and ecosystem impacts. This demonstrates a holistic approach to thinking about the processes of derivation, stimulating innovation to find greener solutions [29].

Dietary fiber and other polymeric compounds are cross-linked with other components of the plant cell wall to form a stricture network. On this basis, water or other more sophisticated means of extraction and methods (like alkaline solutions or enzyme hydrolysis) are required to remove many polysaccharides from the structural composition composed of covalent and non-covalent bonds. The extraction procedure can be difficult due to the structural complexity of dietary fiber and their components. Mechanical and enzymatic techniques have been employed as pretreatments to improve fiber extractability and yields. And one of the most prevalent extractive practices is thermal extraction along with chemical extraction, Figure 2 [30].

Thermal impact on dietary fiber fragments is influenced by the conditions of the process and also by the bonding of polysaccharides to dietary fiber and other cell wall compounds. Heat treatment can release dietary fibers from the cell membrane and dissolve labile substances which are related with dietary fiber structure, such as arabinoxylans, beta-glucans, oligosaccharides, and pectin.

Also, heat treatment can promote the cleavage of glycosidic bonds as a result of elimination of pectin substances, leading to solubilization of insoluble dietary fiber. Processing at high temperatures can change structural pectin or protopectin into soluble forms by hydrolysis, thereby increasing the soluble dietary fiber content. It is worth noting that more intensive processing may lead to degradation of soluble pectin. On the other hand, the reduction of insoluble fiber levels by heat is due to the partial degradation of cellulose and hemicellulose into simpler sugars (primarily glucose and, respectively, xylose and galactose) [31].

Unfortunately, at this period of time there is not enough information about modern and non-thermal methods of obtaining dietary fibers from plant raw materials. Thus, ultrasonic and microwave irradiation was mainly used to increase the yield as a result of extraction.

Extraction caused by microwave radiation - electromagnetic waves of different frequencies are used, which do not cause ionization of atoms and molecules of substance but provoke structural changes in plant cells. This method of extraction results in one-sided processes of heat and mass transfer. Microwave energy acts directly on the material, due to the interaction of molecules with the magnetic field, converting electromagnetic power into heat energy. Then the thermal energy needs to be scattered in the sample volume. These changes increase the permeability of the cells, and the diffusion of compounds internally and externally is what ultimately drives up the efficiency of extraction [32].

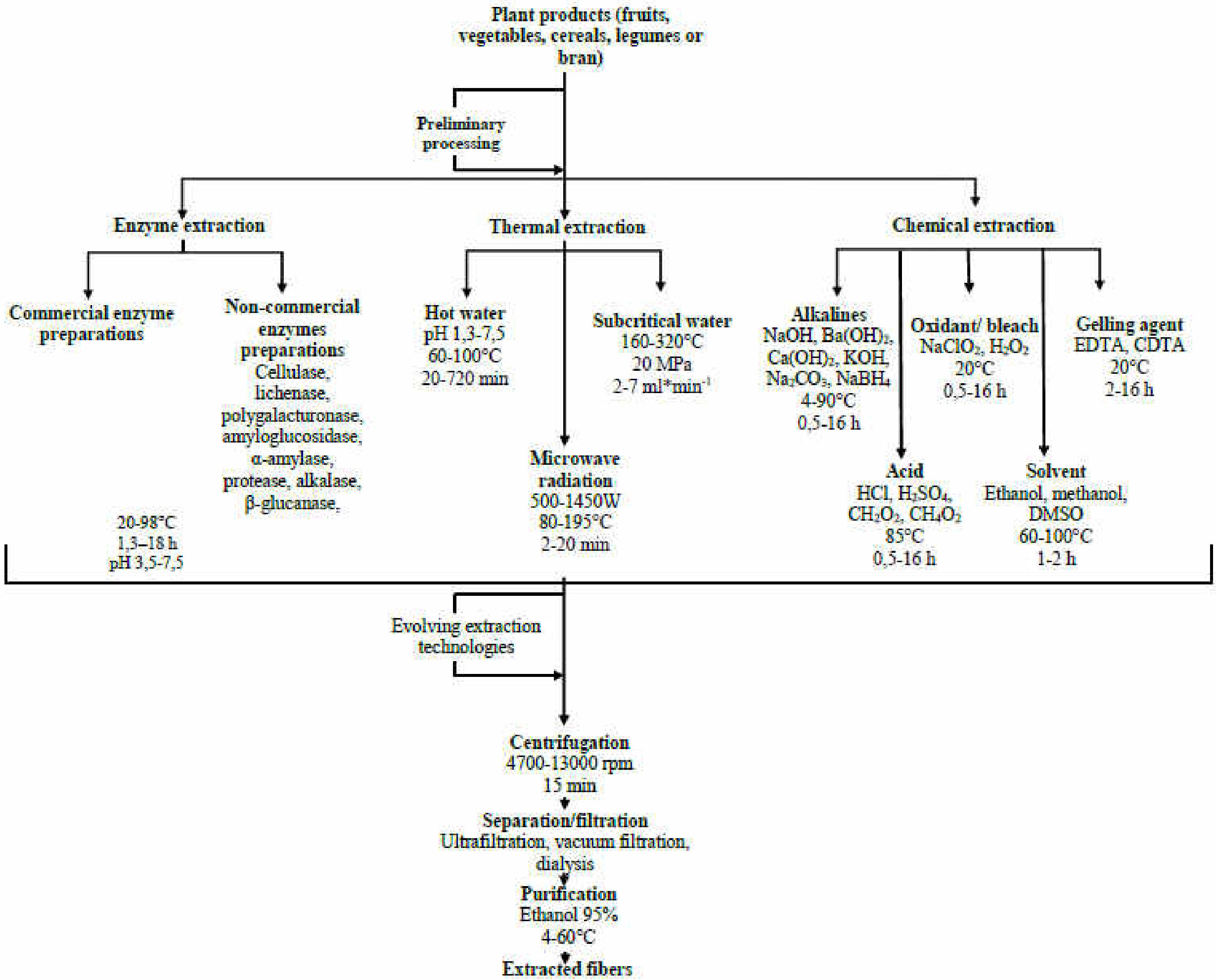

Figure 2. Scheme for extraction of dietary fiber from plant products [30].

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Three-phase separation is a new nonchromatographic method of biological separation, the principle of which is the separation and extraction of simple organic compounds from lipids, by isoelectric precipitation, and precipitation of co-solvents in solutions of tert-butanol and ammonium sulfate. This method is characterized by high efficiency due to the increase in the extract level and low energy consumption, and also allows to preserve the physiological activity of raw materials [29].

Ultrasound extraction involves the use of special devices capable of generating ultrasound to extract bioactive substances. In this process, acoustic cavitation is used, which leads to cell wall damage of vegetation raw materials. This causes an increased release of biologically active components. The principle of action of ultrasound is based on the effect of mechanical waves, which are characterized by amplitude, frequency, intensity, length, power and speed. The frequency of ultrasound waves is in the diapason from 20 kHz to 10 MHz [30]. The advantages of this method are less consumption of solvents and energy, reduced time and heat requirement as opposed to traditional techniques of extraction. Ultrasonic extraction methods have been successfully utilized as a promising method which is gaining an increasingly strong foothold in the food industry. This is determined by a number of factors: the methods are quite cost-effective, environmentally friendly and easy to apply, which contributes to the improvement of food quality as well as the development of functional products. Ultrasound due to cavitation disrupts the cell wall structures of plants, maximizing the access of solvent to all tissues, while microwaves release polysaccharides from cell walls, increasing extract yield [30]. Aqueous extraction methods using ultrasound improved the physical, chemical, microstructural and physiological characteristics of edible fiber recovered from orange, grapefruit and lemon seeds. In addition, ultrasound treatment raised the proportion of soluble dietary fiber extracted from papaya peels [33].

Extraction under the action of a pulsating electric field. This method suggests electroporation, which induces cell wall damage. Pore building causes mechanical degradation of cell walls and the substance is reported to be disintegrated. Factors affecting extraction when subjected to a pulsed electric field include its strength, treatment time, pulse waveform, conductivity, material porosity, solvent ionic strength and pH. The results of using the described method include high extraction efficiency by increasing the diffusion of intracellular materials and the rate of mass transfer [32].

Supercritical fluid extraction involves solvents used at pressures and temperatures above critical limits. Under such conditions, the properties of both liquid and gaseous solvent can be observed. Carbon dioxide is commonly used for supercritical fluid extraction because it has low levels of critical pressure and temperature and is classified as being non-toxic, nonflammable and cheap. Supercritical fluid extraction is predominantly used for separation of lipid fractions from vegetal raw sources [32].

As follows from the above, the potential use of emerging techniques such as ultrasonic and microwave processing for extraction and modification of dietary fiber is evident and should be taken into consideration for more detailed study in future research [30].

5. Role of dietary fiber in human body

Dietary fiber has attracted much attention over the years, due to its potential as a pharmaceutical product because of its ability to lower cholesterol [34], prevent coronary heart diseases and diabetes, prevent the obesity development, and improve intestinal peristalsis, which is particularly relevant to the elderly [35,36]. Dietary fiber is a material that binds potential nutrients, leading to the formation of new metabolites, and may also increase the growth of intestinal villi, increasing the assimilation of substances. A large number of studies have shown that soluble dietary fiber is beneficial to health due to its immunomodulatory and anti-inflammatory effects, and insoluble fiber due to stimulation of intestinal function [37,38].

5.1 Gastrointestinal function

Current research shows that consuming optimal amounts of dietary fiber has beneficial influence on the digestive tract, for example, regulating bowel function, improving glucose tolerance in diabetics, and having a preventive effect for chronic diseases that can cause colorectal cancer [39]. Fiber-rich foods contain a wide range of compounds that may prevent various types of cancer. In addition, some fibers have demonstrated their ability to adsorb carcinogenic agents [40].

The World Health Organization (WHO) has suggested a total fiber consumption of 25 g/day [41]. Nevertheless, actual dietary fiber intake ranges from 14 to 29 g/day. Very few countries report fiber intakes above or at the same level as WHO recommendations. Most values are below national recommendations [42].

Dietary fiber has been shown to influence the intestinal microflora by changing bacterial fermentation activity, composition of colonies and their sizes [43]. Indigestible carbohydrates are the main source of energy for many gut microorganisms and can directly affect species that rely heavily on this substrate [44].

5.2 Cardiovascular system

Dietary fiber may have important effects on the cardiovascular system, influencing the glycemic response and various other aspects of metabolism [45]. These days, a large number of studies report a decreased risk of circulatory system diseases due to regular consumption of high-fiber foods. Some experiments have suggested that dietary fiber may change major cardiovascular disease risk factors, which include metabolism of lipids and lipoproteins, inflammatory signs, insulin homeostasis and coagulation, and improve insulin sensitivity, whereby lowering the risk of cardiovascular mortality [46]. Define in spite of studies have shown positive influence on cardio-metabolic danger factors by soluble gel-forming fiber, dietary sources consisting mostly of non-soluble fiber are still more closely associated with reduced cardiovascular disease risks [46]. The results of the several studies also give the idea that the role of fiber is dependent on its source and type and not on the amount of its consumption [47,48]. Various types of dietary fiber can cause dissimilar effects on physiology; soluble fiber is in control of lowering the level of cholesterol, while non-soluble fiber has contact with the intestinal walls and stimulates its function [49,50].

Many scientific sources support the importance of dietary fiber in developing metabolic health. They lower insulin resistance by slowing down gastric emptying, reducing carbohydrate digestion and absorption, and increasing glucose intake by peripheral tissues [51]. Dietary fiber prevents the onset of cardiovascular disease due to different processes including regulation of weight, better glucose metabolism, control of blood pressure, reduction of oxidative stress and subclinical symptoms of inflammation [52].

5.3 Postoperative recovery

Studies have shown that malnutrition for patients with malignancy is 31-97% [53,54], mostly with gastric cancer, so it is necessary to choose the right dietary therapy for these patients. Preliminary enteral nutritional base is recommended after gastrointestinal surgery. Exist a lot of types of nutrients such as omega-3, probiotics and dietary fiber that can modulate immune function [55]. Short-chain fatty acids are the principal source of energy for intestinal epithelial cells and play an important role in supporting colon activity and inhibiting growth of cells. The amount of these acids is influenced by dietary fiber fermentation in the gut [56]. The use of enteral nutrition can restore intestinal mucosal integrity following surgical procedures [57], and early support of enteral nutrition reduces the risk of infection [58,59]. Leukocytes engage and relocate from the blood to inflamed tissue via multiphase process that requires the activation and expression of some proteins such as chemokines and cell adhesion molecules, and short chain fatty acids modify this process [60,61] by modulating the amount or type of molecule coupling. Such fatty acids may modify leukocyte recruitment, reducing the chronic inflammatory response of the gastrointestinal tract. A couple of researches claimed that early administration of enteral nutrition with soluble dietary fiber may improve nutritional status, delay weight loss in patients and reduce the incidence of digestive complications [62,62]. Thus, dietary fiber intake may reduce the inflammatory response and improve postoperative immune function.

5.4 Problems associated with malnutrition

Satiety is a part of the appetite control system of the body engaged in restricting food intake. Satiety shows in the amount and length of time of food intake. Moreover, it is represented in the quantity of meals and the intervals between meals [64]. Regulating food consumption by eating food products with high nutritional value can be one of the solutions to help decrease obesity. The effectiveness of various types of dietary fiber contribute to satiety differs [65,66]. A growing body of evidence shows that physical and chemical properties of dietary fiber that include water-binding capacity, viscosity, and ferment ability, can lead to reducing food consumption [66,67]. Viscous fiber increase production of saliva and chewing process [56], which may lead to early satiety and reduced food uptake [68,69]. Moreover, fibrous residues improve the metabolism of lipoproteins and lipids by decreasing the rate of absorption of fats, increasing cholesterol fecal excretion and decreasing the synthesis of cholesterol in the liver. Increased fiber intake entails a prolonged feeling of satiety, hence may be important in the fight against obesity [70,71].

Concluding the above, it can be concluded that from a functional perspective, dietary fiber is an essential component for the health improvement of the population. However, due to the lack of population awareness or unwillingness of people to pay proper attention to them, it is necessary to find a way to introduce them into the ordinary life of the inhabitants of both our country and the whole world. Thus, one of the directions may be the enrichment of mass consumption food products with fiber in order to provide the daily requirement for each consumer.

6. Use dietary fiber in food products

Numerous process residues and secondary products generated in the manufacture of treated goods are not properly utilized. Certain of them can be useful as a high source of fiber, thus reducing environmental contamination and at the same time increasing the nutritional value of the foods [72]. Food enrichment with edible fiber, influencing the finished material's rheological properties, is an effective method to improve nutritional and organoleptic parameters, as well as to increase their functionality [73]. Dietary fiber has all the necessary characteristics to be an additional component in the production of special purpose products since its biological activity and physiological value is proven due to its beneficial effects for human health [74].

To date, scientific research that is based on the study and implementation of dietary fiber in food products is more focused on products of animal origin (dairy and meat foods), on flour and confectionery products, as well as on some types of beverages [75]. A few examples from the above industries will be discussed below, with reference to the impact on the quality parameters of finished food products.

6.1 Dairy products

The elevated level of fat in ice cream and frozen yoghurt fulfils certain functions. Examples include the following types of high-fiber substances that replace fat when added to dairy products: guar gum, alginates and cellulose gels. This in turn improves emulsion and foaming, imparts viscosity and stability during freezing and/or thawing, controls melting properties and ice crystal size (mostly small), and simplifies the process of extrusion [76].

Multiple analyses have shown the fact that supplementing dietary fiber in variable amount to yoghurt boosts the nutritive quality including consistency, texture, and general consumer satisfaction [77]. Experimental data showed that yoghurt fortified with inulin from wheat (concentration 1.3%) and apple fiber was a possible alternative increase fiber supplementation and its popularity among consumers also increased [78]. However, the yoghurt to which 3% fiber was added as well had similar measures of sourness and sweetness, firmness and smoothness, and also overall acceptability. This resulted in yoghurt with high organoleptic performance and positive health benefits [79].

An experiment was conducted using pith from apple as a naturally occurring stabilizer and texture former in the production of thermostatic yoghurt. Different apple pomace concentrations (0.1, 0.5 and 1 % by weight) were added to skimmed milk and fermented with a combination of *Streptococcus thermophilus* and *Lactobacillus delbrueckii subsp. Bulgaricus* at 42 °C. The obtained results suggested that the addition of 1% of the squeeze resulted in a significant increase in pH and a reduction in gelation time. What's more, all of enriched yoghurts showed better consistence and connectivity during storage for up to 28 days [80].

The impact of different sources of dietary fiber likewise oats, wheat, apple and inulin on the rheological and thermic properties of ice cream mixes was also investigated. The insoluble fiber content remarkably enhances viscosity and liquefaction of the ice cream by increasing the general solids level and the creation of meshes of hydrated hemicellulose and cellulose. Increasing the soluble content did not essentially modify the samples' rheology, but limited the freezing point decrease, which suggests a possible cryoprotective effect [81]. The supplementation of apple fiber improved the viscosity and increased the values of transition temperature, most notably in the protein’s presence. The implications of the findings indicated that it is possible to potentially use dietary fiber as regulators of recrystallization and crystallization processes in dairy products which have been frozen, i.e., it is possible to influence the malformations such as ice and snowiness of ice cream.

The effect of soluble edible fiber inclusions on the kinetics of milk coagulation was determined experimentally. Before adding rennet, three types of fiber were added to the milk: acacia gum, inulin or pectin. Milk curdling controlled by a voltage-controlled rheometer, near infrared transmissive sensor and hot wire sensor. The gelation time and coagulum solidification rate were identified from the response characteristics of the sensor. Pectin (0.2-0.4 %) significantly reduced gelation time. The addition of pectin at contents above 0.2 % increased the gelation time of the coagulum and lead to limitations in the casein network development [82]. This study may have a positive impact on the manufacture of cheese and other dairy products, subsequently increasing production efficiency.

Inulin, guar gum and pectin are additionally used in the production of cheese to reduce fat percentage and, consequently, to reduce the caloric content of the finished product. At the same time, the addition of these substances does not affect the sensory characteristics of cheese such as texture, flavor, and aroma [74].

6.2 Bakery and confectionery products

Many bakery and pasta products made from flour with added dietary fiber are currently on the market. The introduction of insoluble and soluble dietary fiber has been found to affect the biological and chemical composition, textural characteristics, and cooking qualities as raw so boiled pasta [83].

Usually flour or functional flour products such as biscuits, whole meal bread, muffins contain edible fiber [74]. Fiber supplements have been demonstrated for increasing the values of flour hydration when is in use in bakery products. For instance, apple squeezes, similar to any other source of fiber, enhance the flour water absorption ability. In overall, pomace of apple has the same effect on the rheological characteristics of wheat flour dough as gluten. As the concentration of apple extract increased from 0% to 30%, the density of the cake grew from 0.48 to 0.67 g/cm^3 owing to the water-binding ability of the fiber, which also affected the texture. The volume of the product decreased from 850 to 620 cm^3 and the texture increased from 1.03 to 1.46 kg-force, indicating a decrease in porosity and airiness of the product. The addition of such a squeeze in the preparation of products eliminates the addition of other flavoring elements, as the pomace imparts an enjoyable fruity smell [84]. Apple pomace can also be used in bakery products as a well-source of polyphenols with antioxidant qualities.

Biscuits have a great forbearance for the inclusion of apple pomace, with several research reports revealing a replacement rate as high as 30 %. A not long past investigation utilized hydrated apple pith powder to part substitute flour in the preparation of biscuits [85]. The results of this research demonstrated that with an increase in the substitution level from 0 to 15 %, the physical features of biscuits such as porosity, volume, and diameter decreased dramatically by 25 %, 23 % and 11%, accordingly. Meantime, after substitution, the fruit flavor of the biscuits intensified, and the taste of cereals reduced. It was found that the overall satisfaction of the enriched biscuits decreased, according to an organoleptic assessment, however the acceptability of all processes was higher than 90 % [85].

The contrary impact of the addition of apple pomace on the hardness of bread has been reported in another study. The quality of a traditional Iranian bread (Sangak bread) that contained apple squeeze powder, the specific proportion of which was 1-7 % by weight of flour, was evaluated. The results revealed that adding apple squeeze powder could decrease the firmness of the bread structure and slow down the staling of bread. They came to the conclusion that the most effective percentage of addition of apple pith was 3 %. Additionally, organoleptic testing demonstrated that adding less than 3 % of apple pomace could improve odor [20].

Grape pomace, being a by-product of winemaking, can be a great source of fiber, as mentioned above. For example, in one study dried pomace from red Cabernet Sauvignon grapes was used to produce chocolate spread (a chocolate-flavored paste product). The primary purpose of the analysis was to identify an opportunity of their use as a sugar and milk powder substitute. The by-products of wine production were dried and milled to obtain a powder, which was further integrated into the product. The consequence revealed that as the content of dried grape pomace expanded, and therefore the fiber input increased, the textural parameters of the product deteriorated: the structure of the spread became harder, which reduced the plasticity and elasticity of the finished product. However, when using pomace at concentrations of 3.61%, 5.64% and not exceeding 10%, the consistency characteristics are observed, which are the closest to the control sample according to the standard formulation [86]. Also, such powders are rich in polyphenolic compounds, which, along with dietary fiber, can increase the biological value of chocolate spread, but it should be noted that high concentrations of applied powder (10 g/100 g) have a negative effect on sensory parameters due to the appearance of bitter taste. In conclusion, the author states that dried grape pomace can be used in the production of chocolate spreads as a partial substitute for sucrose, milk powder and whey powder. Among the positive aspects of such an introduction, it can be highlighted the increase in functional properties of the product and the reduced cost. However, the most important technological parameters should be modified (such as, plasticity, particle size and distribution, and others) to comprehensively improve the quality of functional spreads [86].

6.3 Meat products

There is a lack of dietary fiber in meat, thus the main goal of most nutritionists and food scientists is to enrich various meat products with fiber of different origins in order to increase the quantity of biologically active substances. Every day, enriching meat with fiber is becoming more and more popular due to their property of extending the shelf life of the product, its qualities, and various technological characteristics [87].

Natural fiber extracted from soy and beetroot and other polysaccharides like cellulose and pectin are used to improve organoleptic properties of products made of meat and are also suitable for low-fat products [88].

Thus, the addition of fiber to meat products can be a good alternative, as it has a number of technological effects: increasing the moisture retention capacity; it can be a fat substitute, which reduces the overall caloric content of the product; improving the texture and stability of the emulsion; increasing the yield of finished products, which in today's reality is one of the main objectives of producers [89].

An example of additional natural raw materials in the production of meat products can be vegetable dietary fiber. Fiber found directly in fruits can be used as a fat substitute and to improve the texture of meat products by making them juicy and tender. At the same time, the use of raw fruits for saturating meat products with dietary fiber is inefficient. This is due to their high moisture content, which can adversely affect the technological characteristics and microbiological safety indicators in the production process. Thus, it is recommended to use them in small quantities or replace them with dried fruits, which will significantly reduce the moisture content [89].

For example, patties made of buffalo meat were enriched with apple pomace in concentrations 2-8% [90]. The content of dietary fiber, fat and moisture had a significant beneficial influence in dependence of the quantity of natural additives. The same results were obtained in viscosity and cooking yield. Furthermore, textural properties as hardness and thickness were increased. In meat examples with the level of fiber more than 6%, firmness was not enough to form the right shape of patty [90].

The introduction of grape seed extracts (GSE) at concentrations up to 1000 µg/g did not make any remarkable changes in the organoleptic performance of prepared pork cutlets in any of the quality parameters tested but was effective in limiting the intensity of excessive flavor, which is usually associated with the oxidative process of fat rancidity in cooked meat [91]. GSE also reduced off-flavor in cooked beef and pork. Restructured chicken slices with added red grape fine dry particles were accepted as a reference sample. They were given a rate: good up to very good in their organoleptic properties such as texture, taste and appearance. The addition of grape pomace did not affect the acceptability of beef sausages and had relatively high scores from an organoleptic point of view [91].

The following study was aimed at investigating the addition of natural grape fiber with antioxidant properties in the production of hamburger chicken patties. The main parameter of the study was the susceptibility of both raw and cooked samples to oxidation during storage (in the refrigerator at 4 °C). For this purpose, dietary fiber was used at different concentrations (0.5 to 2 %) and analysis was performed on the same day, on day 3, on day 5 and the final analysis was performed on day 13 of storage [92]. The organoleptic characteristics of the product were also evaluated: color, taste and acceptability for consumption. Thus, it was determined that the addition of grape dietary fiber improved the oxidative stability and antioxidant activity of the lipids, thus increasing shelf life, and did not affect the overall palatability of the cutlets. Hence, can be applied as an effective fat oxidation inhibitor for the production of chicken meat products [92].

In another study, fiber microparticles (FMPs) were separately extracted from the plum pulp and peel. There are α- and γ-tocopherols, co-extracted β-carotenes, polyphenols and lutein in the plum chemical composition. FMPs of pulp and peel were appreciated as organic antioxidant additive (at a concentration of 2.0% by weight) in raw chicken breast patties subjected to oxygen influence [93]. FMPs decreased the accumulation of toxic substances of thiobarbituric acid in uncooked cutlets in the time of 10-day storage at 4.0 °C. The iron reduction capacity was 78-158% higher in patties enriched with fiber, mostly extracted from the peel, which has been credited to the antioxidants provided by FMPs [93]. This could also be related with the growing levels of γ- and α-tocopherols observed in the patties with added fiber. In addition, the higher content of pectin and lower lignin content of pulp FMPs are responsible for the greater hydration, stabilization of cyanidin and thus the dark-red color imparted to uncooked cutlets and the higher firmness of prepared cutlets. FMPs from plums pulp and peel are effective supplements for meat products made of chicken [93].

Synthetically derived dietary fiber or preparations of dietary fiber, which also find their application in meat products due to their economic and technological features, can serve as another solution for enrichment of meat products. They provide good water absorption capacity, improve flavor and are cheaper than meat [89].

6.4 Beverage and sauce production

In beverages, natural fiber, mostly soluble, is usually added in order to get higher stability and thickness. These can form gelatinous mass when it contacts with liquids, that increases viscosity of beverages and keeps them from dissociation of their components. Natural fibers that are used for improvement of organoleptic properties are β-glucan, cellulose, and pectin [74].

A small study was also conducted to assess the acceptability of fiber-enriched drinking water and conclusions were drawn based on the organoleptic perceptions of patients at a hospital in Lucknow. In appearance, the fiber-enriched sample did not differ from normal drinking water, but had a faint aroma that increased after drinking, and a pungent taste that left an aftertaste. When analyzing the texture of the samples presented, the fiber-enriched water appeared slightly granular, which could also be felt during tasting, visually the sample did not contain any solvents. In general, fortified water can be a good additional source of dietary fiber, but the unpleasant aftertaste should be neutralized, and the optimal dosage should be determined, and further laboratory analyses should be carried out [94].

Apple pomace is commonly used for light alcoholic drinks preparation in order to make richer and better flavor. The experimenter prepared alcoholic beverages from dried apple extrusion and yeast colonies such as *Saccharomyces cerevisiae*, dry wine yeast accompanied by β-glucosidase ferment and *Hanseniaspora uvarum* [95]. Fermentation lasted 4 weeks and the temperature regime was 16 ± 2 °C. Distillation of the liquids was done twice and the alcohol strength was 20-21% (*v/v*) in the first step and 60 % (*v/v*) in the second one. Each one of the beverages had high level of the alcohol, starting with 261 g/10 m^3 absolute alcohol for *Hanseniaspora uvarum*, to 509 g/10 m^3 absolute alcohol for *Saccharomyces cerevisiae*. Nevertheless, the usage of enzymes was claimed inappropriate due to the excessive methanol concentration [95].

Experiments were carried out on the enrichment of sauces such as Béchamel. Among the different white sauces enriched with apple fiber (AF401), potato fiber (KF200) and microcrystalline cellulose (MCC) were selected [96]. All were formulated by removing milk and corn starch and their replacement with 3% of various natural fiber. The freeze/thaw stabilization of three white sauces with addition of natural fiber was studied by examination of their physicochemical, sensory properties and rheological one in dependence of freezing and defrosting. The sauce enriched with MCC was mostly similar to the control sample (0 % fiber), demonstrating more thermal stability and viscosity. After undergoing freezing and thawing, the viscosities of the samples were as follows (Pa·s): control - 1.45; AF401 - 1.17; KF200 - 1.38 and MCC - 2.03 [96]. Moreover, the MCC-enriched treated samples showed a lower percentage of syneresis compared to the control. For example, the fresh control sample showed a syneresis of 6.88%, whereas the AF401 sample showed 24.9%, the KF200 sample showed 5.72%, and the MCC sample showed 6.68%. The fiber-enriched samples had the strongest matches with the organoleptic properties both before and after processing, with higher creaminess and less heterogeneity. Thus, MCC can be used in sauce preparation for high nutritional value product creation, acceptable for frozen meals, as shown by normal freeze/thaw qualities that are similar to those of a corn starch-based control sample [96].

7. Conclusions

This review paper highlights that dietary fiber are biologically active substances that can serve as an additive to enrich food products in order to make them functionally aimed at preventing many diseases associated with digestive disorders, cardiovascular problems and obesity. It becomes possible to regulate the intestinal absorption of carbohydrates and lipids, accelerate the appearance of the feeling of satiety, improve the quality of the microbiota of the large intestine and therefore immunomodulation. There are a large number of fiber extraction methods that are already widely used practically - chemical, mechanical, thermal and enzymatic.

Studies have indicated an increased use of dietary fiber in products from different food industries. Thus, for the bakery, confectionery and pasta industry, the actual functional products are whole meal bread, biscuits and pasta made of flour enriched with fiber and resistant starch. The addition of dietary fiber provides increased flour hydration values when used in baking, improves the culinary properties of pasta products, and also improves the stability of the emulsion of halva mass and structural parameters of halva.

In the dairy industry, dietary fiber is actively used to replace fat due to their gel-forming ability, to provide viscosity, improve emulsion, foam, freezing stability and biological value, and as catalysts for protein coagulation in milk.

For meat products, the addition of fiber may be due to its ability to increase viscosity, which may have beneficial influence on the structure and juiciness of meat. Dietary fiber can also be used as a fat replacer in dietary sausages to reduce their calorie content and as inhibitors of lipid oxidation in chicken meat to increase the storage life of products made from it.

It is possible to enrich drinks, which will improve their biological value and prevent the precipitation or separation of ingredients, and various sauces, which entails an increase in their stability during freezing and thawing, therefore, it is possible to store them for a long time without losing their organoleptic properties.

Thus, thanks to dietary fiber, it is possible to increase the range of functional food products and to solve a number of problems related to the irrational use of food industry waste in the Republic of Moldova. However, it is necessary to continue the study of dietary fiber, which can be obtained not only from fruit raw materials, but also from other sources (vegetables, legumes and cereals) in order to identify more positive aspects or possible risks of their introduction into foodstuffs. In addition, there is a need to review the functional foods already consumed with dietary fiber in order to determine their acceptability for the population and future generations, as well as the rationality of their use for producers, for the country's economy and for the preservation of the ecosystem through the possibility of ensuring zero-waste production.

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