Review

Dietary Fiber and Prebiotic Compounds in Fruits and Vegetables Food Waste

Corina Pop ¹, Ramona Suharoschi ^{1,2} and Oana Lelia Pop ^{1,2,*}

¹ Department of Food Science, University of Agricultural Sciences and Veterinary Medicine, 400372 Cluj-Napoca, Romania; coryna181@gmail.com (C.P.); ramona.suharoschi@usamvcluj.ro (R.S.)

² Molecular Nutrition and Proteomics Laboratory, Institute of Life Sciences, University of Agricultural Sciences and Veterinary Medicine, 400372 Cluj-Napoca, Romania

* Correspondence: oana.pop@usamvcluj.ro

Abstract: The fruits and vegetables processing industry is one of the most relevant food by-products, displaying limited commercial exploitation entailing economic and environmental problems. However, these by-products present a considerable amount of dietary fiber and prebiotics with important biological activities, such as gut microbiota modulation, lowering the glycemic load and replacing some unhealthy ingredients with an impact on food texture. Therefore, the international scientific community has considered incorporating their extracts or powders to preserve or fortify food products an area of interest, mainly because nowadays consumers demand the production of safer and health-promoting foods. In the present review, literature, mainly from the last 5 years, is critically analyzed and presented. A particular focus is given to utilizing the extracted dietary fibers in different food products and their impact on their characteristics. Safety issues regarding fruits and vegetables wastes utilization and anti-nutritional compounds impact were also discussed.

Keywords: food by-products; fruits waste; vegetables waste; dietary fiber; prebiotics; food products fortification

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1. Introduction

Consumers' preoccupation with healthy food is in continuous growth, taking the same trend with the authorities' concerns regarding food sustainability [1]. Dietary fibers and prebiotic compounds, present in fruits and vegetables, considerably improve human health through mechanisms, such as microbiota modulation, reduction of postprandial glycemic response, normalizing the cholesterol level, preventing constipation, transporting the phenolic compounds, and so on [2–7]. The Food and Agriculture Organization (FAO) and the literature reports that approximately 40% of fruits and vegetables are lost after harvest and prior to retail stages, and approximately 50% after retail, generating needs for low-cost and sustainable solutions [8–10]. Fruits and vegetables wastes involve edible and inedible parts that, for specific reasons, get removed from the food supply chain (crops, inadequate deposition, hospitality, domestic, etc.) [11,12]. A part of these plant-based wastes can be avoided or partially avoided with management optimization. Unavoidable plant fruits and vegetables receive new destinations or are removed as garbage.

An interesting and well-documented systematic review reveals that the generated food loss and wastes are most studied, and probably the most crucial tool in this management is digital technologies [13]. Furthermore, the same group reveals in another recent systematic review, focused on the food waste produced in the educational institutions, applicable and realistic anti-food-waste strategies [12].

Reutilization of fruits and vegetables wastes and by-products [14], or taking the maximum out of them by extracting valuable compounds that can be further used in functional foods or in nutraceuticals may be the most promising approaches with positive impact on the environment, the food industry and finally, on consumer's health [15–20].

Further we are discussing the dietary fiber and prebiotics content in fruits (apples, cactus, citrus and exotic fruits) and vegetables (cabbage, artichokes and carrots), their extraction and impacts on food products. The authors have made a novel contribution to the research of food waste combat and reduction strategies by identifying the latest dietary fibers and prebiotics extraction methods, sources, and potential utilizations, underlying safety concerns valid for future researches (Figure 1).

Figure 1. Overview of the review objectives.

2. Rationale for Research-Data Collection and Processing

2.1. Search Strategy

The relevant papers based on our objective regarding dietary fibers and prebiotic compounds from plant residues were followed in the present study.

The studies analyzed during the research were identified by searching the following databases: Microsoft Academic and Google Scholar.

The search had limited articles published between 2015 and 2021.

The search strategy included the main keywords:

- Vegetable/Fruits residues/by-products/wastes from fruits (apple tescovina, citrus, cactus, cabbage, artichoke, carrot tescovina).
- Wastes/by-products dietary fibers.
- Wastes/by-products prebiotics.
- Adverse effects of dietary fiber.
- Anti-nutritional compounds in vegetable/fruits residues/wastes/by-products.

For each of these keywords, we tried to find as many synonyms and words with possible connections as possible.

2.2. Inclusion and Selection of the Study

For the selection of the studies, two main concepts were followed, namely the debate of the topic of interest and their quality. Finally, the generated articles were selected manually first by examining the title, then reading the abstracts. A process in which articles that did not refer to the topic were excluded. The articles that were included after the examination were subjected to the research of the text.

The evaluation of the quality of the articles was based on aspects, such as clarity, the way of perception in which the data and the obtained results were collected, and their coherence. The analyzed data were extracted and grouped according to the chapters of interest.

3. Extraction and Identification of Dietary Fiber and Prebiotic Compounds from Food Waste

The origin of the dietary fiber in fruits and vegetables is found in the walls of the parenchyma cells. At a technological maturity, cell walls have the ability to provide soluble polysaccharides, such as pectic polysaccharides, but also cellulose, together with xyloglucans, insoluble fibers, heteroxylans and galactoglucomannans in small quantities. Vegetables provide a higher fiber intake compared to fruits, especially insoluble ones, such as cellulose and lignin [21]. Dietary fiber obtained from plant residues associated with various compounds, especially polyphenols and carotenoids, is a new area of interest [22].

3.1. Dietary Fiber and Prebiotic Compounds from Fruits Wastes

3.1.1. Apple

The by-products resulting from the processing of apples represent 25–30% of the total fruit being formed from the peel, pulp and seeds. For a long time they were used as animal feed or composted [23]. Apple pomace has a higher content of dietary fiber compared to the apples themselves. It is estimated that 100 g of pomace contains 4.4–47.3 g of dietary fiber, the values varying depending on the use of different varieties of apples and their extraction methods. The ratio between soluble and insoluble fibers also varies depending on the apple varieties used to obtain pomace [24].

One of the best known methods of extracting dietary fiber from pomace is achieved by multi-phase cleaning, grinding, micronization and finally pasteurization [25].

Extraction of fibers by steam explosion and the response surface methodology led to a major increase in the extract. At a steam pressure of 0.51 MPa for 168 s and a sieve mesh size of 60, the yield reached 29.85%, an increase of 4.76 times higher than untreated apple pomace. Steam blast pretreatment increases fiber functionality, water retention capacity and swelling capacity [26].

Extrusion has been applied and studied in recent years for the modification of apple pomace. It has been shown that the yield of water-soluble polysaccharides increases, insoluble fibers can convert to soluble fibers by partial solubilization of non-pectic cell wall polymers, and hot water-based pectin extraction is also facilitated by extrusion application. The results showed increased functional properties, water solubility increased by up to 33%, water absorption 22% and viscosity 20 times compared to the highest thermo-mechanical treatment. The increase of the thermo-mechanical treatment determined a decrease of the soluble fibers and an increase of the insoluble ones until soluble fibers with small molecules at the maximum speed of the screw. Extrusion has molecular and macromolecular changes to the structure, resulting in increased porosity leading to increased water absorption. The extruded material can be used for the production of food, but further studies are needed to regulate the technical and functional properties [27,28]. The storage of fibers in polyethylene, aluminum bags and glass jars at low temperatures is favorable in the long run [29].

3.1.2. Cactus

The cactus fruit is called pitaya, or dragon fruit, which is part of the genus *Hylocereus* from which several species are derived.

Cactus fruit residues represent 25–30% of the total fruit mass. Studies have shown that the residues contain a large intake of dietary fiber, phytochemicals and natural dyes. The predominant fibers found in the residues were cellulose, hemicellulose, simple sugars and pectin [30].

The determination of dietary fiber in the powder of unbleached residues by acid or alkaline digestion showed a percentage of 26.97% and 28.45%, respectively. The reaction observed during the drying process was pectin degradation [31]. The extraction of pectin was performed by transforming the residues into paste, followed by the addition of acidified water at a pH = 3.5 and a temperature of 85 °C for 5 h. A maximum yield of 26.82% dry matter was obtained, the main components observed being carbohydrates [32].

Oligosaccharides from cactus fruit residues are a mixture of fructose and oligosaccharides with prebiotic properties [33]. The determined carbohydrates showed a degree of polymerization similar to that of inulin, also present prebiotic properties in the fermentation of microbial cultures [34].

The oligosaccharide powder can be obtained by distillation using a rotary evaporator for which 80% ethanol and a temperature of 60 °C are used. The extraction was diluted with distilled water in a ratio of 1:1 and the remaining ethanol was removed by redistillation, the extraction having 20° Brix. Fructose and glucose were removed using a *Saccharomyces cerevisiae* yeast strain BCC 12652 (28 ± 2 °C), 48 h, followed by broth filtration, followed by centrifugation to remove solid particles and yeast cell fractions. The concentration was determined by spray drying [35].

Nopal or *Opuntia* is considered a functional food due to bioactive compounds, such as polyphenols and ascorbic acid and the high content of dietary fiber. The prebiotic character is due to the high content of soluble and insoluble fibers and the mucilage containing arabinoxylans that shape the intestinal microbiota [36]. The amount of fiber is 50%, of which 26% is soluble, such as pectin and gums, and 74% is insoluble, such as cellulose and lignin [37].

3.1.3. Citrus

Citrus fruits are part of the largest category of fruit crops in the world; worldwide there are an estimated 88 million tons of which only a third are processed. Oranges, grapefruit, lemons and mandarins represent this category in 98% of industrialized crops. Residues generated by the citrus industry consist of bark, pulp and seeds. The shell consists of albedo, or the inner part of the mesocarp, and flavedo. Albedo represents the white, spongy and cellulose tissue being considered the main component of the shells for obtaining dietary fibers [38]. Dietary fiber obtained from citrus pomace is characterized by high water retention capacity and a special viscosity [39].

Alcohol extraction is a standard fiber extraction method, but it has the disadvantage of producing new insoluble fiber-rich residues. To recover these fragments of dietary fiber, an ethanol wash was used using by-products obtained from mandarins, which were applied as carriers of probiotics. The study results showed that a large amount of dietary fiber remained in the residue after ethanolic washing, due to the protein-fiber interaction and phenolic compounds bound in association with the fibers. Tangerine residues compared to other matrices responded best to the protection of probiotics from thermal shock. This is due to their ability to absorb proteins [40].

One way to modify dietary fiber is with the help of alkaline hydrogen peroxide treatment and homogenization treatment. The extraction took place in two ways, the difference between them being the time of maintaining the suspension in water. The suspension was obtained by treating the residue with deionized water at a pH of 1.7 adjusted with a saturated solution of oxalic acid, after which it was introduced into the water bath at 70 °C, 2 h and 80 °C, respectively, for 1 h. The mixtures were centrifuged for 15 min, then dried at 60 °C for 4 h, powdered and kept in a desiccator at ambient temperature until treatment with alkaline hydrogen peroxide and homogenization. The results of the study showed an increase in water retention and swelling capacity. When applying the homogenization treatment, the fibers have a higher water retention, swelling and oil retention capacity, the values being higher than the chemical treatment. Treatment homogenization degrades the crystal structure of the resulting fibers and weakens the internal structure which, when the chemical treatment total fiber content increases, degrades the hemicellulose and lignin part [41–43].

3.2. Dietary Fiber and Prebiotic Compounds from Vegetables

3.2.1. Cabbage

The residues resulting from the processing and cultivation of cabbage are 20% consisting of leaves, core and outer leaves that are discarded due to pests [44]. Carbohydrates are

found in a proportion of 90%, a third being dietary fiber [36]. Chinese cabbage residues are dried, ground, and passed through a sieve for the enzymatic production of soluble dietary fiber. The powder was treated with a mixture of 1 M NaOH and 1.5 L Celluclast enzyme. 85% ethanolic alcohol at 80 °C was used to separate the soluble and insoluble fibers, after which the powder was incubated for 40 min at 60 °C, then filtered [45].

Another method of obtaining fibers is wet grinding, in which the cabbage is pre-crushed with the help of a mill in which the water used has a pressure of 4.8 bar. The puree obtained is bleached with citric acid in a concentration of 1.2% and homogenized. Manual wet sieving with distilled water followed. The fibers concentration consists of the freezing under pressure of the obtained paste and its fractionation [46].

Red cabbage has undergone several drying treatments to obtain dietary fiber, such as natural drying in the sun, in the hot air oven and freeze-dried. The research results showed that the highest percentage of fibers were extracted from sun-dried cabbage followed by baked and finally freeze-dried [47].

3.2.2. Artichoke

Global artichoke production is estimated at 1,450,000 tons per year, ranking sixth in cultivated vegetables. A considerable amount is discarded, a percentage of 80–85% (Boubaker et al., 2016). Artichoke by-products consist of leaves, bracts and stems. These by-products are rich in inulin, a polysaccharide that can be processed by digestive enzymes that can hydrolyze the lack of fructans [48].

Two methods of extracting dietary fiber from artichoke residues were compared to note the rheological functions. The methods used for the extraction of citric acid and citric acid together was the enzymatic treatment after a pre-heating step. The fibers obtained by extracting the citric acid with the enzyme exhibited a lower viscosity and less-structured gels [49].

Another method of extracting the fiber pre-treatment is the application of heat, the addition of hemicellulose and precipitation with ethanol and the precipitate is finally lyophilized. The extracted fibers exhibited a higher activity that stimulates the activity of intestinal bacteria, the presence of prebiotic carbohydrates for the activity of the fibers [50,51]. Another prebiotic compound was extracted from the residue of the oligosaccharide using a probe ultrasound sonicator by that shown in addition to a high extraction efficiency and energy savings in economic terms [52].

3.2.3. Carrot

After processing, approximately 50% of the raw material resides as follows. The most promising dietary fiber extraction methods were compared and determined by ultrasound extraction at higher extraction yield [23].

Carrot pomace contains a large amount of fiber, cellulose being in the highest percentage present 51.6% followed by lignin 32.2%, hemicellulose 12.3% and finally pectin 3.88% [53].

Recent research had focused on the composition of polyphenols related to dietary fiber. Defenolized dietary fiber and dietary fiber without actions on the phenolic composition were compared, and the results showed that defenolized fiber has a lower action of antioxidant and prebiotic properties. Forty-two polyphenolic compounds found in dietary fiber were found [54,55].

Pectin was extracted from black carrots by several methods, using a microwave, ultrasound, and conventional heating. Microwave extraction had the highest extraction efficiency, followed by conventional heating. Extraction using conventional heating is preferred when higher antioxidant activity is desired due to a higher concentration of anthocyanins in pectin [56]. Citric acid solutions with adjustments of pH, temperature, time and liquid-solid ratio were used to extract the pectin from the common carrot [57].

Ball milling was used to increase the absorption capacity of the fibers to reduce the particle size to have a more significant impact as a prebiotic ingredient. The mill obtained

has hydrating capacities, glucose ions, nitrites and lead through an increase in absorption capacity, which results in greater activity of protection of intestinal cells [58].

4. Applications of Dietary Fiber and Prebiotic Compounds from Food Wastes

Consumer demand is growing to consume foods enriched with natural supplements that bring health benefits [59]. Consumption of dietary fiber in a larger amount helps prevent and reduce cardiovascular disease by lowering cholesterol and triglycerides and gastrointestinal problems. It is recommended to ingest 20 g–35 g/day dietary fiber in healthy adults [60]. The incorporation of insoluble and soluble fibers is mostly used in products with solid consistency, and in liquid products, soluble fibers are most desirable. The products in which dietary fiber is most often applied are pastries, beverages, dairy products, frozen dairy products, pasta, meat and soups. Food processing by-products are the main sources rich in dietary fiber but research is limited [61]. Food meant to be a source of fiber, and any other statement which may have the same meaning for the consumer may appear on the food package only if the product contains at least 3 g of fiber per 100 g or at least 1.5 g of fiber per 100 kcal. A food shall be rich in fiber and any other indication which may have the same meaning for the consumer only if the product contains at least 6 g of fiber per 100 g or at least 3 g of fiber per 100 kcal.

4.1. Fruits Waste Dietary Fiber and Prebiotic Compounds Applications

4.1.1. Apple

Traditionally, apple pomace is used as animal feed [10]. Since it does not contain phytic acid and can restore minerals, apple pomace has an advantage compared to cereal bran; it could be used as a stabilizer in oil-water emulsions [62].

For the incorporation of pomace powder into bakery products, cookies were used. The sensory characteristics had been improved, the aroma and taste were accepted by tasters. The physical characteristics were more or less affected depending on the amount of powder used, and a significant increase was observed in the rheological characteristics, especially in the hydration capacity [63–65]. Another product in which the powder was added is the cake top, which was compared with a control sample (cake top obtained with wheat flour); from a sensory point of view, the top with powder obtained from apple pomace showed a higher percentage, higher accessibility and lower texture appreciation, being harder and smaller in volume [66].

In the dairy industry, a study was carried out by which the pomegranate powder was incorporated before the fermentation operation to obtain yogurt. The study showed that powder increased the pH during gelation and shortened the fermentation time, the yogurt having a firmer and more consistent texture during storage. These effects are due to the gelling effect of pectins, insoluble fibers released in milk. From a sensory point of view, tests are still needed to determine consumer acceptability [67].

In the meat industry, the powder obtained was incorporated into a mixture of buffalo meat used for hamburger [68] and in chicken sausages [69,70]. A decrease in water retention capacity was observed while cooked.

4.1.2. Cactus

In the biscuits, the powder obtained from the dragon fruit residues was added in a proportion of 50% and the other half wheat flour, providing a five times higher increase in fiber in the product [71].

In the dairy industry, the powder has been used as a fat substitute in strawberry ice cream, using the fruit of the red dragon. The rheological properties and the degree of melting were not influenced and from an organoleptic point of view it was accepted by consumers. It was also added to pasteurized milk to determine the antioxidant action. Pasteurized milk with added powder from dragon fruit residues can be kept for 12 h at room temperature [72].

Cactus fruit powder was added to boiled sausages inoculated with lactic acid bacteria. In boiled sausages, the powder caused a high humidity and in those with lactic acid bacteria the humidity was lower, but the structure was harder and less cohesive and resistant. The use of powder has led to a decrease in oxidative rancidity during storage. The difference in texture is determined by the production of exo-polysaccharides by the strain used. The use of this powder for its components, fiber, prebiotics and antioxidants helps the development of thermotolerant bacteria of lactic acid [73].

4.1.3. Citrus

Dietary fiber obtained from citrus by-products has a high water retention capacity that benefits from viscosity and multiple applications in food. They play an essential role in glucose homeostasis, lowering total liver lipids and maintaining intestinal health [39].

Dietary fiber from orange peel was added to the orange juice to study the in vitro bioavailability of flavonoids and their ability to inhibit glucose transport in cells. The research study showed that flavonoids were able to inhibit glucose transport in cells. The addition of fibers due to the non-covalent interaction between fibers and flavonoids increases bioavailability, but limits their availability to interact with intestinal glucose transport [74].

Also, the pectin obtained from citrus powder is used in the pharmaceutical field because it helps to dilute the matrix for faster drug release [75].

4.1.4. Exotic Fruits Waste

Pomegranate: Nowadays, consumers look at dietary fibers as healthy ingredients. This fact leads to the development of new and innovative products. Gül and his colleagues used pomegranate seed flour in bread with acceptable results for percentages up to 5%. An increased fiber contends, but no impact on antioxidant activity was registered [76].

Mango: mango peel (10–15%) was used in corn chips proving improvement of sensorial properties (color, odor, flavor) and texture compared with the non-supplemented ones or the ones supplemented with 20%. Besides the mentioned characteristics, the chips proved higher antioxidant activity, with almost 50% bioaccessibility for the phenolics and lower glycemic index [77]. Another food matrix where mango peel is used (5 g/250 mL), with good stability ad sensorial an instant drink [60].

Even if, usually, mango peel is seen as waste, important nutritional valorization can be obtained due to its high content in fiber and micronutrients, with good potential for utilization in different food matrices [60,78].

Banana: Banana peel pectin properties (methylation degree, molecular weight, sugars compositions and gelling ability) are directly influenced by the extraction parameters and the pH. This pectin proved good consumer acceptability, used in a salad dressing as a fat replacer [79].

Pineapple: Pineapple fruit wastes are rich in dietary fibers, protein, fat, carotenoids and polyphenols. Steaming under pressure increases all these nutrients availability. A study demonstrated that the pineapple wastes can be used as an ingredient in a mixture of pork/turkey meats in potential functional Vienna-type sausages with good physical properties [80].

Feijoa: Almeida and its colleagues used feijoa peel flour as an excellent source of insoluble dietary fibers (xylose, xyloglucans galactomannans and pectin), magnesium, calcium and phosphorus suggesting as food applications functional and nutraceutical products, including gluten-free ones [81].

4.2. Vegetables Waste Dietary Fiber and Prebiotic Compounds Applications Cabbage

The powder from the white cabbage residues brought rheological benefits to the cake and bread top, as well as elasticity and a more uniform uniformization and dispersion of the pores. A descriptive sensory analysis was done by 13 trained tasters in order to evaluate the textural sensory characteristics. From a sensory point of view, color, taste

and smell were slightly modified but accepted, the products having advanced quality characteristics [82].

The replacement of nitrates with Chinese cabbage powder in pork sausages resulted in a lower cooking efficiency. Powder addition printed the product a redder color, reduced the cooking yield and the pH values. Addition of Chinese cabbage powder can be a promising natural alternative for sodium nitrate with applications in the meat industry [83].

4.2.1. Artichoke

The high-fiber powder obtained from artichoke by-products was incorporated into biscuits. From a sensory perspective, biscuits were accepted, even if they had a darker color (Jose et al., 2017). In white bread inulin was added extracted from artichoke residues; in a low concentration, it has minimal effects on the rheological properties of bread, but also significant effects on health due to prebiotic capabilities [84].

The action of artichoke residue powder as a phosphate substitute in emulsified chicken meatballs was studied. The results showed that the use of powder together with baking soda improved the physical, chemical, technological and sensory characteristics [85]. Powder was added to the low-fat yogurt, which improved the yogurt nutritionally due to inulin and mineral salts, enriching the microbiota. In addition to its prebiotic properties, it is also recommended as a fat substitute in yogurt [86].

4.2.2. Carrot

The powder obtained from carrot pomace has the most applications in pastry. It had positive effects on biscuits, improving the texture [87], as well as on biscuits enriched with cowpea flour, in which a major increase in nutrients was observed [88]. The effect of Persian gum and carrot pomace powder for the development of low-fat donuts was studied, due to the water retention capacity of the additives, the absorption of fats during frying significantly decreased [89]. Also, the gluten-free cake incorporation in larger quantities has led to a more acceptable taste, texture and color [90]. The powder from the carrot residues was mixed with corn flour to obtain the corn tortilla, causing an increase in elasticity [91].

In the drinking yogurt, it was incorporated to increase the amount of fiber. The defects detected were on the smell, creaminess and taste. Strawberry flavor and coloring were added to improve them [92]. It had positive effects on fatty yogurt, being used in small quantities compared to yogurts without addition [93].

An inverse emulsion of olive oil and powder was made to partially replace the fat in the meat. The results of the study showed that total fats and saturated fats decreased but unsaturated fatty acids increased, which helps to increase the nutritional ratio [94].

A carrot and apple pulp powder was incorporated into fish sausages to increase the fiber content. Powder incorporation has improved texture, increased water retention capacity and cooking efficiency [29]. Carrot pomace powder was also incorporated into typical sausages (Table 1) [95].

Table 1. Recent (last 5 years) reported utilizations of fruits and vegetable wastes dietary fibers and prebiotic compounds in different food products.

Food Product	By-Product	Formulation/Storage Conditions	Dietary Fiber/Prebiotic Compound	Key Outcome Information			References
				Optimal Dosage (s)	Impact on Sensorial Characteristics	Other Impacts	
Bread	Pomegranate seeds	Powder	Dietary fiber: lignin, cellulose.	5%	The biggest changes were noticed in the color of the crust, smell and taste.	The rheological characteristics were slightly modified.	[76]

Table 1. Cont.

Food Product	By-Product	Formulation/Storage Conditions	Dietary Fiber/Prebiotic Compound	Key Outcome Information			References
				Optimal Dosage (s)	Impact on Sensorial Characteristics	Other Impacts	
Cake	Potato peels	Powder (drying→grinding)	Dietary fiber	5%	No major changes in the product were noticed, just more darkness color.	Increasing the strength and elasticity of the dough.	[96]
Donut	Carrot pomace	Powder (drying→grinding→sift)	Dietary fiber: pectin, lignin, cellulose, hemicellulose	6.45%	The sample showed a smaller volume. Consumers have suggested adding a glaze.	Significant impairment of physico-chemical properties.	[89]
Biscuits	Carrot pomace	Powder (whitening→grinding→sif)	Dietary fiber: pectin, lignin, cellulose, hemicellulose	10%	-	Neutralization of free radicals.	[88]
Eriste (Turkish noodle)	Grapes, pomegranates, rosehips seeds	Powder (grinding→sift)	Dietary fiber	10%	The sample enriched with pomegranate seed powder obtained the highest appreciations from a sensory point of view.	Increase in antioxidant activity.	[97]
Corn chips	Mango peels	Powder (freeze drying)	Dietary fiber	10–15%	Improving and maintaining the smell, texture, color and aroma.	Increasing the content of total phenolic compounds.	[77]
Ice cream	Red pitaya peels	Powder (grinding→sift)	Dietary fiber: pectin, lignin, cellulose, hemicellulose	1%	Melting rate and color were not affected.	Improving rheological qualities and increasing nutritional value.	[98]
Ice cream	Grapefruit peels	Stem-shaped crystals	Nanofibril cellulose	0.4%	Texture improvement.	Reducing caloric intake.	[99]
Agitated type yogurt	Carrot pomace	Powder	Dietary fiber: pectin, lignin, cellulose, hemicellulose	1%	The color and smell of the sample were affected and strawberry flavor was added to improve them.	Reducing syneresis.	[92]
Agitated type yogurt	Apple pomace	Powder (lyophilized)	Dietary fiber: pectin	1–3%	Increasing firmness and viscosity.	Reducing the release of whey.	[100]
Salad cream	Banana peels	Solvent extraction	Pectin	2%	The sauce incorporated with pectin extracted with acid, showed a higher acceptability and a decrease in viscosity.	Decreased rheological properties.	[79]

Table 1. Cont.

Food Product	By-Product	Formulation/Storage Conditions	Dietary Fiber/Prebiotic Compound	Key Outcome Information			References
				Optimal Dosage (s)	Impact on Sensorial Characteristics	Other Impacts	
Chocolate	Grapes pomace	Powder (drying→grinding→sift)	Dietary fiber and prebiotic compound: lignin, cellulose, oligosaccharide	3–5%	At a higher dosage there is a slightly bitter taste due to phenols. The greatest impact on the product occurred in the particle size.	Water activity and stability increased.	[101]
Instant drinks	Mango peels	Powder (bleaching→drying with hot air)	Prebiotic compound	5 g/250 mL	During storage, the sensory characteristics decrease.	Improvement of phytochemical parameters and stability increases during storage.	[60]
Vienna sausages	Pineapple pomace	Powder (pressure steaming→lyophilized or hot air dried)	Dietary fiber: lignin, cellulose, hemicellulose	-	-	The reducing effect on nitrites, moisture, shear strength and shrinkage was obtained in sausages, while carotenoids and antioxidant polyphenols increased.	[80]
Buffalo meat	Apple pomace	Powder	Dietary fiber: lignin, cellulose, hemicellulose	6%	The firmness increased, and the color became redder and darker.	Increased cooking efficiency, water retention capacity, pasta diameter.	[68]
Flour	Feijoa peels	Steam discoloration→ice bath→drying in a convective oven→grinding	Dietary fiber: lignin, cellulose, hemicellulose	-	-	Alternative source of bioactive ingredients.	[81]
Powder	Olive pomace	Liquid-enriched pomace powder(the liquid fraction was lyophilized and the solid fraction was dried)	Dietary fiber: pectin, lignin, cellulose, hemicellulose	-	-	Food preservative and source of mannitol.	[102]
Powder	Fine particles obtained from cold processing of vegetable oils	Degreasing→drying	Dietary fiber	-	-	Source of dietary fiber with strong antioxidant properties.	[103]

5. Safety Issues and Anti-Nutritional Compounds of Dietary Fiber and Prebiotic in Food Waste

In addition to the many benefits to the body, dietary fiber also has some adverse effects. They interact with some nutrients and inhibit their absorption into the digestive system. By exceeding the fiber intake/day, the absorption of minerals in the small intestine is reduced, reducing the transit time that does not allow the absorption of minerals. They also form mineral-fiber complexes that cannot be broken and absorbed. The sudden transition from a low-fiber to a high-fat diet causes bloating, flatulence, nausea and vomiting. Also, a high-fiber diet leads to nitrogen loss compared to a low-fiber diet [104].

Irritable bowel syndrome is characterized by abdominal pain and bloating. People who suffer from this syndrome and include a higher intake of protein-rich dietary fiber in their daily diet have more severe symptoms of bloating [43,105]. Inflammatory bowel disease is a chronic inflammation of the intestinal tract. The causes of this disease are the symbiotic disturbances between the host's immune system and the microbiota. Factors that influence the intestinal microbiota are diet and dietary fiber, intervening dysbiosis [106]. Inulin inhibits reduced intestinal Ca^{2+} absorption during treatment with proton pump inhibitors, but Mg^{2+} uptake did not increase until serum Mg^{2+} was recovered [107].

People with colorectal cancer are not given a high-fiber, prebiotic diet, especially insoluble ones, to reduce the symptoms or mortality of the disease [108].

Potential contaminants (toxins, mycotoxins) that can be entrained in the extraction process need to be considered when discussing the safety aspects of dietary fibers and probiotics from fruits and vegetables wastes consumption. Fruits and vegetables are a very good nutritional environment, which allows the development of pathogenic microorganisms able to produce mycotoxins.

Anti-nutritional factors are secondary metabolites, these being biologically active to some extent [109]. They are found in most plants as by-products of the processes that lead to the synthesis of primary metabolites. Anti-nutrients have been developed to form a protective shield against fungi, insects and predators [110]. The classification of anti-nutrients can be undertaken in two main groups: thermo-stable and thermally labile. Other classification methods would depend on their chemical structure, specific action and biosynthetic origin, but these classifications do not include all known groups of anti-nutritional factors.

The most common anti-nutrients are cyanogenic glycosides, inhibitory enzymes, hemagglutinins, plant enzymes (urease, lipoxygenase), goitrogens, estrogens, saponins, tannins, amino acids, alkaloids, anti-metals, anti-vitamins, favism factors [109,111]. Citrus residues have considerable values of anti-nutrients. Phytic acid has the highest concentration, followed by tannins and oxalates [112,113].

Banana peels are rich in phytates, alkaloids, oxalates and hydrogen cyanides, but researchers claim that the concentrations are within safe limits; these are recommended for use in industry [114,115].

Oxalate, phytic acid, saponins and tannins have been identified to extract pectin from apple peels [116]. The seeds are rich in amygdalin, but in oil extraction by a supercritical fluid at pressures less than 30 MPa, it was not detected [117].

The amount of phytic acid and oxalates was higher in mango peel than fruit pulp [118]. Pomegranate residues have a high tannin content which presents safety problems [119]. In the pineapple peel, phytic and tannic acid is present, requiring processes to reduce the anti-nutrient content [120]. Also, cactus pear seeds are rich in phytates, tannins and oxalates [121].

Cabbage leaves contain many anti-nutrients, such as tannins, oxalates, phytic acid and cyanide. Cyanide is in small quantities and does not cause adverse effects; instead, the other compounds have safety problems, so treatments must be applied to reduce them [122,123]. Anti-nutritional factors are compounds that reduce the availability of nutrients, digestion, absorption and production of side effects (Table 2), so some processing methods are needed

to reduce or eliminate them [124]. The most commonly used methods for reducing or removing anti-nutrients are shown in Table 3.

Table 2. Adverse effects of the most present anti-nutrients from plant residues.

Phytochemical Factors	Human Body Reactions	Anti-Nutritional Effects	References
Tannins	Binding of bacterial enzymes form indigestible complexes with carbohydrates	decreased taste intensity, affects digestion	[125,126]
Phytic acid	Forms insoluble complexes with zinc, copper, calcium and iron resulting bad absorption	-	[126]
Oxalates	In the body they combine with divalent metal cations such as calcium and iron to form oxalate crystals that are excreted in the urine	tissue damage, kidney stones form	[127]
Saponins	Erythrocyte rupture and hemoglobin release	-	[128]
Phenols	After ingestion, they are part of the xenobiotic metabolism and are conjugated with glutathione, sulfate, glycine or glucuronic acid	nausea, vomiting, headache, abdominal pain, sore throat, mouth ulcers and dark urine, as well as respiratory and cardiovascular effects may occur	[129]

Table 3. Methods of elimination or reduction of anti-nutrients.

Processing Method	Working Parameters	Reference
Bleaching	Soft boiling at 75–95 °C	[130,131]
Autoclaving	Working temperature above 100 °C or 121 °C	[130,132]
Extrusion	Careful control of humidity, temperature and speed of the mold and screw	[133]
Frying	Dry heating at 120–150 °C	[132]
Dipping	Use of water and salt solutions with or without additives to facilitate the process	[132,134]
Chemical processing	Treatment with thiols, sulphites or calcium salts	[132,135]

6. Conclusions and Perspectives

Our narrative review presents studies on dietary fibers and prebiotics recovery from fruits and vegetables wastes and by-products. We address aspects, such as recovery and extraction procedures, characterization and utilization in different food matrixes. In addition, essential elements, such as nutritional impact (i.e., minerals absorption) affect the sensorial characteristics of specific foods, the possibility of replacing some unwanted ingredients and safety and anti-nutritional aspects are also discussed.

Literature results show different protocols for adding the extracted dietary fibers and prebiotic compounds in various food products (bakery, dairy, meat and fish products). However, the results are not homogeneous. We strongly believe that systematic reviews can facilitate implementing such protocols on specific compounds and food products.

Finally, fruits and vegetables by-products capitalization is an excellent alternative when aspects of safety and anti-nutritional compounds are under control.

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