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Review

Application of Agri-Food By-Products in the Food Industry

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Abstract: Every year, the global food industry produces a significant number of wastes and by-products from a variety of sources. By-products from the food-processing sector are produced in large quantities, and because of their undesirable qualities, they are frequently wasted, losing important resources. In order to pursue a circular economy that refers to waste reduction and effective waste management, by-products valorization recently received increased interest. By-products are rich in bioactive compounds and can be used in various industrial applications for health promotion and nutritional benefits. A novel step in its sustainable application is the use of these inexpensive waste agri-food by-products to create the value-added products. The present review intended to summarize the different types of agro-industrial by-products and their properties and highlight their nutritional composition and potential health benefits. Applications of agri-food by-products in foods as well as the potential health and sustainability implications of by-products in food products were also covered. According to research, agri-food by-products can be added to a variety of food to increase their bioactive profile, fiber content, and antioxidant capacity while maintaining good sensory acceptability. Overall, the sustainability of the agri-food chain and consumer health can both benefit from the use of agri-food by-products in food formulation.

Keywords: agriculture-food secondary products; bioactive compounds; food industry; sustainability; value-added products

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1. Introduction

Taking into consideration global environmental concerns and resource scarcity, the food industry is increasingly becoming aware of the importance of sustainable practices and reducing waste. It gained significant attention that agri-food by-products are valuable resources with an untapped potential that were once viewed as waste materials.

The European Union (EU) established an action plan to eliminate food waste, using a circular economy as a method [1]. It involves a strong emphasis on reducing, reusing, recovering, and recycling materials and energy in order to raise the value of goods, materials, and resources, and extending their economic usable life. The Food and Agriculture Organization of the United Nations [2] emphasizes the importance of reducing carbon footprint in sustainable agriculture. Reducing agriculture's carbon footprint is a top priority, with sustainable practices such as precision agriculture, organic farming, and enhanced management of manure playing a crucial role in combating climate change. In addition, studies have shown that low-value agri-food wastes, co-products, and by-products enhance soil quality in a variety of ways and are essential for closing the nutrient loop [3].

Agri-food by-products, which are generated during the various phases of agricultural and food processing operations, contain numerous nutritional, functional, and bioactive components, which can be used to develop innovative food products, reduce waste, and improve the overall sustainability of our food systems [4].

Several studies recently highlighted the fact that agriculture-food by-products have a huge potential to be used in a variety of food applications, such as utilizing them for obtaining bioactive compounds, developing alternatives for livestock feed, and using them in new food formulations. Due to the abundance of proteins, lipids, carbohydrates, micronutrients, bioactive substances, and dietary fibers in this situation, food wastes and by-products are of utmost relevance [5–7].

There has been a great deal of interest in efficient agri-food by-product utilization in recent years because it is capable of enhancing sustainability, minimizing waste disposal, and creating value-added products within the food industry. There has been considerable interest among researchers and industry professionals, as well as policymakers in this field as a result, which led to a significant increase in scientific investigations and technological advancements. The food industry can become more environmentally friendly and resource-efficient by adopting a circular economy approach, which can end up turning underutilized by-products into valuable ingredients, functional additives, and feed sources, by adopting a circular economy framework [8].

Many studies highlighted in the past few years that agri-food by-products have immense potential to be used in diverse food applications, such as the extraction of bioactive compounds, developing alternative feed sources for livestock, and utilizing them in innovative food formulations [4,9–12]. In spite of this, there are still several challenges relating to technological limitations, consumer acceptance, marketability, and regulatory constraints, even though interest is growing. Achieving sustainable food systems requires harnessing the potential of agri-food by-products in order to make the food system more resource efficient and sustainable. Figure 1 provides an overview of some of the prospective applications of high added-value compounds derived from agri-food wastes and by-products in the food and healthcare industries, as well as some of the technical issues that need to be considered for those applications to be carried out effectively.

In order to capitalize on these opportunities, the food industry can contribute significantly to waste reduction, environmental protection, and the creation of innovative and sustainable food products through taking advantage of these opportunities [13,14].

This review highlights and summarizes the current literature pertaining to the different types of by-products the nutritional composition of agri-food by-products, the potential health benefits, waste management approaches, and the development of functional foods. The enhancement of nutritional and functional attributes of by-product-based value-added products has been discussed in detail.

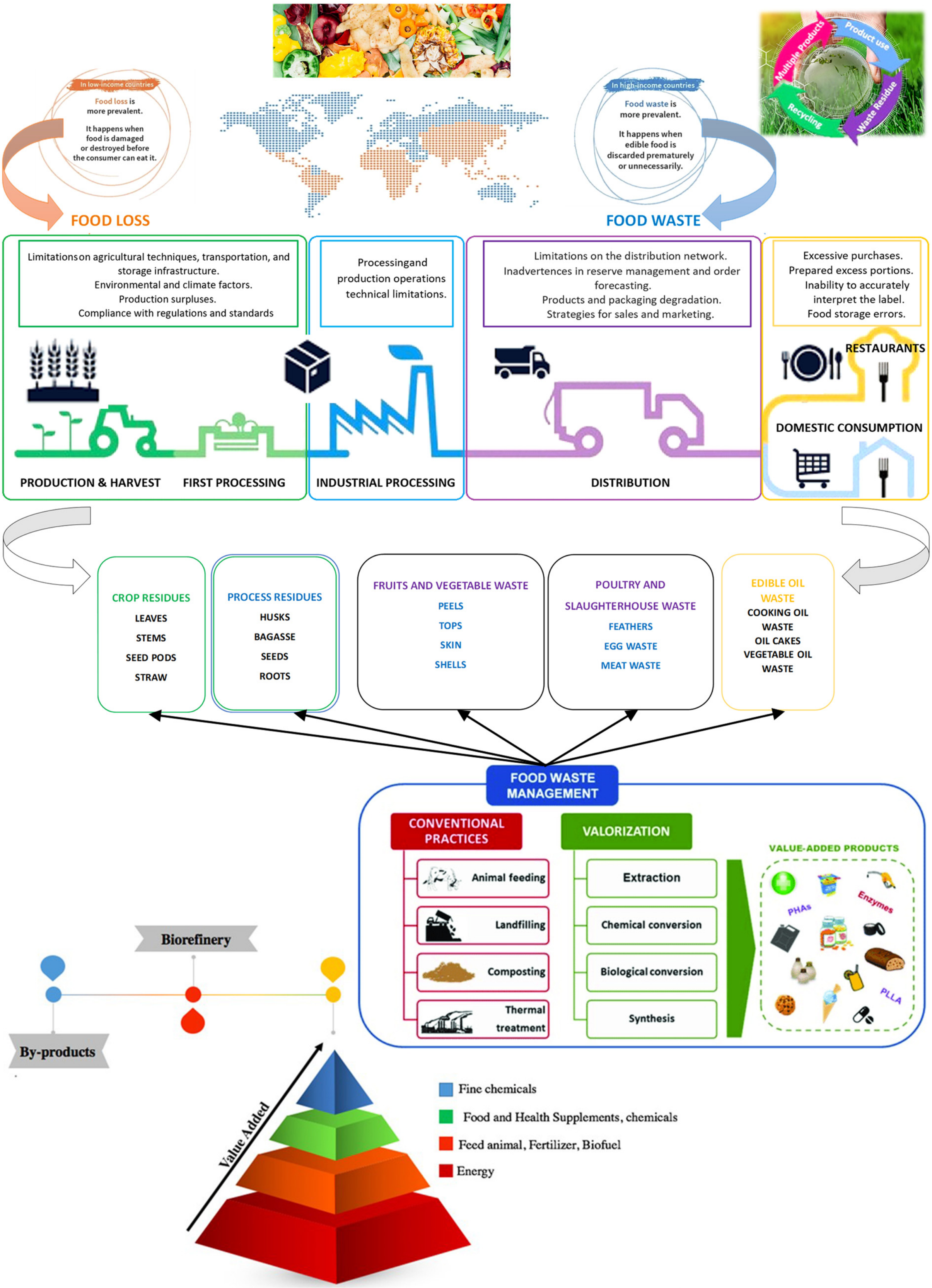

Figure 1. Interaction of waste fruit and vegetable matrices for the purpose of environmental remediation [15–17].

2. Agri-Food By-Products and Their Properties

Worldwide, the agri-food industry produces over 190 million tons of by-products each year [18]. Damaged raw materials, pomaces, leaves, seeds, shells, brans, oilseed cakes, molasses, and other by-products of the processing process are examples. The disposal, recycling, or waste management of these is extremely important. However, the majority of these food by-products may be valued for profit depending on their nature and amount [19].

Plant-based by-products have a high nutritional value in terms of carbohydrates, proteins, phytochemicals, and/or antioxidants when compared to other agro-industrial residues. The two primary categories of agro-industrial by-products are agricultural and industrial. Field residues and process residues are additional categories for agricultural residues. Field residues are by-products from the crop harvesting process that remain in the field. While the process residues are still present even after the crop is processed into another useful resource, the field residues are made up of leaves, stems, seedpods, and stalks. Molasses, bagasse, husks, seeds, leaves, straw, stems, stalks, shells, pulp, peels, roots, and other substances make up these wastes, which are utilized for making fertilizers, animal feed, manufacturing, and several other purposes. Every year, the food processing sectors, including the juice, chips, meat, confectionery, fruit, and vegetable industries, produce a significant quantity of organic wastes and associated effluents [20].

Pulp, peel, seeds, skin, pomace, husks, pods, and stems are examples of by-products produced in the fruit and vegetable industry that represent the majority of the agri-food by-products. Fruit and vegetable by-products, which is easily generated in large quantities can be recovered and used as value-added products. All of these by-products have considerable levels of dietary fiber and bioactive compounds (polyphenols, carotenoids, glucosinolates, etc.) in their basic composition. Because of this, the food sector may find it appealing to valorize by-products in order to produce components with nutritious value [21].

Researchers are looking for new uses for these by-products because of this, as well as the growing concern of representatives to encourage the change of the food system through a sustainable production model and the implementation of more sustainable lifestyles by consumers. The studies concentrated on the application of circular economy models, which reintroduce by-products as new products into production chains [22].

Proteins, carbohydrates, lipids, and other bioactive components like phenolics, dietary fibers, alkaloids, and pigments are present in substantial amounts in a number of agri-food by-products. The recovery of valuable compounds from vast quantities of by-products can have an influence on the economy, environment, and sustainability of food worldwide. Utilizing large-scale manufactured plant-based food by-products is economical for industry, needs less waste disposal, and expands the range of products available, such as functional foods and the development of high value-added compounds. The food industry and researchers are looking for new ways to evaluate plant-based food by-products in light of these benefits [23].

2.1. Some Examples of Agri-Food By-Products

Agro-industrial by-products are produced at all points along the food supply chain, including during agricultural production, processing, and distribution. They are primarily made up of seeds, peels, stems, leaves, and useless pulp from fruit and other vegetable sources. Food waste is also produced simultaneously, and a specific by-product can be recognized as well as wasted food, such as fruit pulp that is discarded from a final product but is otherwise suitable for consumption. Up to 42% of it occurs within the household, 39% in the food manufacturing sector, 14% in the food service industry (restaurants and ready-to-eat food), and 5% during delivery [24].

One of the most popular commodities consumed worldwide is fruit and vegetables, which make up more than 44% of all food waste. Instead of being thrown away, by-products can be utilized as functional food additives, specifically for formulations that are rich in antioxidants. As a by-product of the pomegranate juice and concentrate industries, pomegranate peels and seeds offer a variety of medicinal and nutraceutical benefits. The oil extracted from pomegranate seed waste contains significant levels of dietary fiber and conjugated fatty acids [25].

Apple by-products, such as seeds and peels, account for around 25–30% of the weight of the initial fresh fruit and are utilized as food ingredients. Apple pomace is a waste or by-product of the processing of apple fruit. It contains a higher percentage of total dietary fiber (74%), as well as functional qualities (swelling capacity, water and oil holding capacity, density). Apple pomace is a significant source of healthy bioactive compounds, such as flavonoids, phenolic acids, flavanols, anthocyanins, dihydrochalcones triterpenoids, minerals, and carbohydrates (pectin and pectin oligosaccharides [26]. The most significant parts in apple pomace are cellulose and hemicelluloses, which make up 43% and 20–32%, respectively [27]. Additionally, apple by-products contain phenolics, which are mostly found in the seed and peel as chlorogenic acid and phloridzin. According to Rabetafika et al. [27], their composition includes anthocyanins (cyanidin-3-galactosides) and flavanols (epicatechin and catechin).

Depending on the variety, processing techniques, and growth conditions, 1–10% of the seeds, 60–65% of the peel, and 30–35% of internal tissues (juice sac residues and rag) from processed citrus fruits were discarded from the total by-products. These fractions represent 50–70% of the processed fruit [28]. The fiber content of orange pomace was mostly high, and these fibers were well suited for products that needed better water/oil holding and binding capabilities, such as a high-water hydration capacity. Pectin is an essential component recovered from the peel that is often extracted using nitric acid and utilized mostly as a gelling agent. With a high dietary fiber content (40.47%), low fat level (2.14%), and a high mineral content, it had a beneficial nutritional makeup [29].

Grapes are a popular fruit that are consumed practically everywhere in the world. Winemaking or vinification accounts for about 50% of the world's grape production. Pomace (skins, stems, and leftover pulp) and grape seed, which makes up over 20% of the original grape weight, are the principal by-products of wine manufacturing [30]. By-products of wine production are a cheap source for developing of dietary supplements and contain a variety of biomolecules (dietary fibers, lipids, proteins, and natural antioxidants and phenolic compounds). Although many important fractions and components can be extracted from grape pomace and other winemaking by-products, the majority of studies focused on phenolic compounds. Phenolic acids, monomeric and polymeric flavanols (proanthocyanidins), and flavanols, as well as anthocyanins in the case of press residues from red grape varieties, are the main types of polyphenols found in grape pomace. Another main by-product is grape seed, which has many bioactive ingredients as stilbene, tannins, gallic acid, resveratrol, catechinalate, and rutin [31]. Anthocyanins from red grape pomace have a long history of use in food preparation, and these extracts are permitted as food additives. In addition, because resveratrol, procyanidins, and anthocyanins are thought to have positive effects on human health, extracts or fractions of these compounds have been employed in dietary supplements. The production of ethanol [32], recovery of dietary fiber [33], production of grape seed oil and pomace oil [34], and other uses for grape pomace have all been reported.

Many industrial by-products are produced during the processing of bananas, including peels, sheaths, stems, leaves, rhizomes, and inflorescence. Banana peels are a great source of carotenoids, phenolic compounds, dietary fibers, and other phytochemicals with strong antioxidant potential. Approximately 35–40% of the mass of a banana is made up of the fruit's main by-product, banana peel. The phenolic chemicals, dietary fiber, and antimicrobial, antibacterial, and antioxidant capabilities found in banana peel are in high amounts in banana peel [35]. Banana peel contains vitamins (vitamins C and A), trace minerals (iron and zinc), and macro minerals (potassium, calcium, phosphorus, and magnesium). The peel contains about 50% fiber and is a major source of pectin, which produces gels that are used as emulsifiers [36].

Depending on the variety and size, processing mango fruit into various value-added products results in enormous waste products, of which peels make up 12–16%, seeds make up 10–25%, and kernels make up 15–20% [37]. Mango peels constitute 10–20% of the mango fruit's overall weight, are the primary by-product of industrial utilization, and are consumed raw. Bioactives, like vitamin C, β-carotene, polyphenols, and dietary fiber are abundant in mango by-products [38]. Due to their high concentration of bioactive substances with useful and medicinal qualities, such as polyphenols, kaempferol, catechins, quercetin, gallic acid, mangiferin, and benzoic acid, mango peels recently caught the attention of scientists. Although mango seed kernels are high in necessary amino acids, they are deficient in proteins. Additionally, it is a good source of phytosterols, tocopherols, and polyphenols. Mango seeds have potential as functional ingredients since they naturally contain antibacterial and antioxidant properties. The oil from mango seed kernels is particularly beneficial; it has a ratio of 52–56% unsaturated to 44–48% saturated fatty acids [39]. A notable source of phenolic acids, flavanols, and anthocyanins, which are all known for their bioactivities as antibacterial and antioxidant substances, is plum pomace [40].

The primary purpose of using the by-products from the processing of vegetables like tomatoes, onions, and carrots is to recover secondary plant metabolites and high-molecular-mass components from the plant cell wall. According to Valle et al. [41], the tomato pomace, which is made up of the peels and seeds, contains about 60% fiber, 25% total sugars, 20% proteins, 8% pectin, 6% total fat, and 4% minerals. The extraction of carotenoids, particularly lycopene, from tomato pomace has been the subject of numerous investigations. Lycopene is gaining popularity due to its capacity to fight cardiovascular illnesses, as well as its antioxidant and carcinoprotective characteristics. Additionally, tomato pomace includes a substantial amount of carbohydrates, particularly glucose and fructose, and is high in fiber, primarily insoluble fiber [42].

Investigations on the by-products of industrial onion processing focused on recovering phenolic substances and dietary fiber. According to reports, the onion skin is abundant in total phenolics, flavonoid, flavonol, quercetin, aglycone, fructans, and alk(en)yl cystein sulphoxides, and it also has anti-inflammatory, antibacterial, antispasmodic, and anti-diabetic properties. Benitez et al. [43] evaluated the effects of pasteurization and sterilization on the stability of important compounds and demonstrated that these side streams represent a source of dietary fiber, fructans, and alk(en)yl cysteine sulfoxides. According to Perez-Gregorio et al. [44], quercetin glycosides predominate among the polyphenols found in onions and their by-products. A rich source of α-carotene and β-carotene is carrot pomace, a by-product of the manufacture of carrot juice. With a soluble-to-insoluble fiber ratio of 1:4, the fiber fraction is the most prevalent in carrot pomace, as it is in other by-products. The presence of carotenoids in carrot pomace, particularly β-carotene and phenolics, makes it particularly important [45].

Beetroots are used to make processed foods like juice, pickles, and ready-to-eat meals. Peels and pomace, which are produced as waste, can be used to extract high-value nutraceuticals or bioactive components. According to Vulic et al. [46], beetroot pomace extract contains phenolic acids, flavonoids, and betalains that have strong antioxidant and hepatoprotective properties.

A by-product of many industrial potato operations, peels, are a common occurrence among other wastes as potato by-products. Due to its high concentration of phenolic compounds with known health-promoting effects, potato peel is a rich source of bioactive compounds mainly phenolic acids and glycoalkaloids [47]. Due to their ability to induce cytotoxicity and apoptosis in several cancer cell lines, potato peel glycoalkaloids are also gaining importance [48]. Ncobela et al. [49] found that potato peel had a crude fiber content of 61.0 to 125 g/kg dry matter.

Studies about the use of additional by-products, in addition to the aforementioned by-products, which are the most common, will also be discussed in the following section.

2.2. Nutritional Composition and Potential Health Benefits of Using Agri-Food By-Products in Food Products

According to Salim et al. [50], the global population is projected to reach 11.2 billion by the year 2100. To meet the needs of this estimated population and resolve food security and environmental concerns, it is crucial to reduce food waste and maximize the use of food resources. The nutritional assessment of fruit and vegetable waste indicates that most of these crop residues and by-products can be used, recovered, and turned into food products with added nutritional value. Therefore, adding value to these residues via drying technology and extraction methods to produce dehydrated products and nutraceutical products, as well, might serve as an alternative market solution for the food and associated industries. In turn, this can generate additional economic opportunities and improve both environmental and social benefits for producers, processors, and consumers [50]. In a study carried out by Ayala et al. [51], it was mentioned that fruit by-products such as bagasse, trimmings, peels, shells, stems, seeds, and bran represent over 50% of fresh fruit and sometimes have a higher nutritional or functional content than the final product. However, these plant-waste products incorporate biomolecules including proteins, vitamins, minerals, aromatic oils, and antioxidant compounds [52]. It is important to consider the composition of by-products from the agri-food sector when developing a strategy to utilize them. These by-products can be a rich source of dietary fiber (DF), phenolic compounds, organic acids, carbohydrates, micronutrients (vitamins and minerals), proteins, and fats in this regard.

2.2.1. Dietary Fiber

Dietary fibers have an essential role that is important in managing and enhancing human health, especially that of the gastrointestinal system. Insoluble fiber is crucial for intestinal control because it promotes mechanical peristalsis. Dietary fibers have significant functional capabilities as food additives due to their effects on binding flavor components, swelling capacity, water retention capacity, gel formation, and increased viscosity. Additionally, because of its ability to water holding and swelling, a dietary fiber derived from agro-industrial by-products is a significant cholesterol-lowering agent [53].

Due to its physicochemical characteristics, which are directly related to its physiological implications, dietary fiber has been the subject of numerous studies. The polysaccharides of the cell wall, which are mostly made up of cellulose, hemicellulose, pectin, and other substances such gums, starch, oligosaccharides, and lignin, are the primary components of DF. Based on their solubility in water and buffer systems, they are divided into soluble dietary fibers (SDFs) (gums, pectins, fructans, inulins, and certain hemicelluloses) and insoluble dietary fibers (IDFs) (cellulose, some hemicelluloses, lignins, and arabinoxylan) [54].

The most prevalent biopolymer in nature is cellulose, which is present in large concentrations in stems, straw, and peels. Banana stems make up 42% of cellulose, maize straw 51%, and onion and oat peels 41% and 39%, respectively [9].

After cellulose, hemicellulose is the second-most widespread component in lignocellulosic biomass, and it may be found in grapefruit waste (6%), chokeberry (34%), cherry (11%), citrus peel (10%), and blackcurrant pomace (25%) among other plant materials [55]. Apple pomace contains 35–60% dietary fiber (lignins 15–25%, pectins 5–10%, cellulose 7–40%, and hemicelluloses 4–25%) [56]. Apple and tomato pomace contain 51.1% and 64.1% of total dietary fiber, whereas citrus, mango, and tomato peels include 67.4%, 69.9%, 64.3%, and 86.2% of total dietary fiber, respectively. Total dietary fiber content in seeds ranges from 2.9 to 26.3%, which is lower than that in pomace and peels; however, it ranges from 35 to 90% in undifferentiated by-products [57–59].

According to various analytical and extraction techniques, pectin is largely present in fruit and vegetable peels, making up 8–53% of orange peel, 1–17% of lemon peel, and 2–16% of grape skin [60]. Legume seed coatings contain between 65 and 86% dietary fiber serving as an alternative source of functional ingredients [61,62]. The development of functional foods with a high nutritional value and various potential health benefits from the conversion of plant fruit processing by-products into compounds with high added-value is an encouraging solution for managing fruit waste product management issues [53]. In terms of health-promoting benefits, grape pomace extract has numerous properties, including cardio-protection, anticancer, anti-inflammatory, anti-aging, and antimicrobial properties. Its high dietary fiber content promotes glucose absorption, obesity prevention, blood cholesterol reduction, and reduced cardiovascular risk [63]. Additionally, grape pomace is an excellent source of fiber for the food sector, with a greater potential for modulating digestive functions and retention of water [64].

In order to lower the caloric content of jam without affecting its sensory qualities, soluble fibers are also utilized in the production of jam [65]. Fiber is added to food, including beverages, to replace the fiber that has been removed during industrial processing, which lowers the amount of sugar in the final product. The peel of the mango is a good source of nutritional fiber as well. Mango peel flour can be used to make pasta (macaroni), bakery goods (bread, cakes, and cookies), dairy goods (cheese, yogurt, and ice cream), and extruded foods. All of these food items are quite important in the global food economy [66]. According to Kohajdova et al. [67], the addition of beetroot powder to bakery products resulted in an enrichment of fiber with favorable effects on the farinographic and physical characteristics and a decreased caloric density. According to Mattos et al. [68], grape by-product extracts have also been employed as natural antioxidants and antibacterial agents in foods (meat products and fruit juices). Apple pomace were demonstrated to be effective stabilizers for oil-water emulsions in a study by Huc-Mathis et al. [69]. Banana peel flour, which is obtained at various stages of ripeness, is a useful functional component. When compared to bread made entirely of wheat flour, bread that incorporates banana peel flour exhibits significantly lower glycemic and hydrolysis indices [70]. Citrus fiber improved the bacterial survival and growth of the investigated probiotics (*Lactobacillus* and *Bifidobacterium* spp.) in fermented milks [71]. Citrus pectin is used in numerous foods, including jams, jellies, marmalades, and other products, as a thickener, emulsifier, and stabilizer [72].

2.2.2. Phenolic Compounds

Phenolic compounds comprise a vast range of amphipathic chemicals (>8000 distinct known molecules). More structurally complicated phenolics are referred to as polyphenols, even though they always share at least one aromatic ring with one or more hydroxyl substituents [73]. The aromatic or benzyl rings of polyphenols may have one or more hydroxyl groups connected to them. In most cases, polyphenols are bound to sugars by β-glycosidic bonds to a hydroxyl group (O-glycosides) or an aromatic ring's carbon atom (C-glycosides). The largest and most extensively researched class of polyphenols are flavonoids, which have structures made up of two aromatic rings connected by three carbon atoms to form an oxygenated heterocycle. Flavonoids are subdivided into a number of subgroups based on the degree of hydroxylation, oxidation, and saturation of the core pyran ring, including flavan-3-ols, flavonols (quercetin, kaempferol), flavones, isoflavones, flavanones, and anthocyanidins. The second largest group of polyphenols are non-flavonoids. They consist of phenolic acids, hydrolysable tannins, coumarins, stilbenes, and lignans, and they have a more simple chemical structure than flavonoids [74].

Those compounds are well recognized for their antioxidant effects, which may inhibit or postpone oxidation by lowering the concentration of transition metal ions (mostly iron and copper) and free radicals. Antioxidants are also employed in the food sector to maintain flavor and color by preventing the oxidation of their components [53]. According to Acosta-Estrada et al. [75], this group of compounds provides various health advantages including antioxidant, antibacterial, antiviral, and anti-inflammatory characteristics. Blackcurrant, cranberry peel, apple pomace, cherry, cactus peel, mango peel, and grape peel are a few agro-industrial by-products remarkable for their high phenolic content [10]. Bananas include catechin and gallocatechin, apple and grape pomace contain proanthocyanidins and flavonoids, and carrot pomace contains hydroxycinnamic derivatives such chlorogenic acid [76]. When exerting different biological processes where an antioxidant quality is desired, these and other by-products might be utilized. They can be utilized completely or further processed to separate and concentrate their chemical constituents, and have been considered to be of special interest for use in preserving or fortifying food products.

During a study on bioactive compounds, it was determined that the peel and seed of mango were the highest in concentration. It was found that the seed contained a total of 37.29 mg of gallic acid/g, 35.954 mg of quercetin/g fresh weight, and 93.4% of DPPH-free radical scavenging activity at a concentration of 307 mg/mL. Compared with the peel, which contained 5.997 mg, 4.455 mg, and 47.97% of DPPH-free radical scavenging activity at a concentration of 322 mg/mL, these amounts were found in the seeds [77]. Yu et al. [78] used colorimetric, chromatographic, and spectrophotometric assays to characterize the phenolic composition as well as antioxidant activity of seven medicinal and dietary plants, including sage, rosemary, olive, pomegranate, rue, peppermint, and parsley leaves and young stems. The study results revealed that pomegranate leaves have strong antioxidant activity due to their high tannin content and variety of phenolic compounds, while the other six plants have phenolic acids and flavonoids with high contents. Thus, they concluded that the pomegranate leaf might be a more valuable plant source of naturally occurring biologically active compounds for developing innovative functional food-pharma compounds that promote human health, bio-valorization, and the environment. The availability of accurate data on the biological functions of bioactive compounds from winery by-products enabled their identification as essential agents for various benefits associated with the prevention of degenerative disorders via their incorporation into functional foods, nutraceuticals, and cosmetic products [79]. Vinification residues are a good source of bioactive chemicals; however, the amount of phenolics and their compound identity and relative proportion depend on the residue type. The discovery of the winery wastes specific polyphenols led to the creation of larger valorization panels for these residues. Recycling vineyard co-products or side streams, then, gives the pharmaceutical, cosmetic, nutraceutical, and food industries important materials, lowering manufacturing costs and having a smaller negative impact on the environment [79]. Also, the study published in 2020 by Nieto et al. [80] emphasized the advantages of utilizing grape stems as a source of natural phenolic antioxidants by using green extraction technology as part of a sustainable food system, which validates the investigation conducted by other authors [81,82].

Another by-product is represented by the peel of citrus fruits, which contains a significantly higher concentration of phenolic compounds and ascorbic acid compared to the pulp [83]. The extraction of polyphenols from citrus by-products aroused the interest of researchers due to their large amounts and multifaceted properties, such as anti-inflammatory and anticancer effects, in addition to their antioxidant activity and other health benefits [84]. Moreover, the peel along with various residues and by-products of pomegranate, banana, and citrus were evaluated by various authors as potentially useful sources of antioxidants [85,86]. According to Szabo et al. [87], the phenolic compounds discovered in banana peel have antioxidant properties that include preventing the formation of reactive oxygen species (ROS), directly scavenging reactive oxygen species, and inducing antioxidant enzymes.

Apples and apple-derived products incorporate a significant number of polyphenolic compounds (phenolic acids, flavonoids, and procyanidins) [88].

The significant phenolic content of apples and apple by-products (powder and extracts) enables the production of final products with enhanced antioxidant benefits without altering their sensory characteristics. Furthermore, proper use of apple by-products reduces the negative impact on biodiversity, contributing also to economic growth [89]. Apple pomace, a by-product rich in vitamins, fibers, phenolic compounds, pigments, and minerals, plays a significant role in the human body due to their impacts on metabolism [87]. These elements can assist in the treatment of gastrointestinal conditions, decreasing the levels of serum triglycerides and levels of LDL cholesterol, and the regulation of glycemia. Additionally, phlorizin, a phenolic compound extracted from apple pomace, has many medicinal properties, especially in diabetes due to its ability to influence how glucose is absorbed and excreted [87,90].

2.2.3. Carotenoids and Tocopherols

The antioxidant pigments known as carotenoids and tocopherols, which are both precursors to vitamin A and vitamin E, respectively, are lipid-soluble [91]. According to functional classification, carotenoids are divided into two categories. Due to the oxygen present in their structures, xanthophylls like lutein, zeaxanthin, and cryptoxanthin are considered oxygenated derivatives. The other group is called carotenes, and it consists of α-carotene, β-carotene, and lycopene, which are hydrocarbon derivatives without any group linked to their structure [92]. Carotenoids are potent antioxidants that help to slow down the consequences of aging, which are linked to the loss of cellular activities over time. They also act as a preventative measure for other oxidative stress-related illnesses like osteoporosis. Effects against skin, ocular, and vascular ageing have been specifically shown, primarily as a result of the protection against cellular oxidation provided by their capacity to scavenge free radicals [93].

Carotenoids and chlorophyll were shown to be abundant in green pea pods and have potential applications as functional additives in food products [94]. β-carotene, an orange pigment, has been found in tomato skin and seeds, as well as in the by-products of sweet potatoes, carrots, and other vegetables. Red pigment lycopene has also been discovered in significant quantities in tomato by-products [95]. High concentrations of bioactive substances, such as β-carotene (32.6 mg/kg), ascorbic acids (111.89 mg/kg), and lycopene (174 mg/kg), are present in tomato processing waste (skin and seeds) [96]. Carrot by-products have also been found to contain β-carotene, and α-carotene. Carotenoids and chlorophylls, together with other phenols, play a significant impact in a food product's color and acceptance, in addition to their health-promoting qualities, suggesting that legume by-products could be developed as food colorings [97].

2.2.4. Proteins

The most important macromolecules for forming body muscles are proteins, which are also a requirement for many other body molecules. Several fruit and vegetables' non-edible parts and waste have been identified as good sources of protein, including the following: apple pomace (4.45 g), mango peel (9.5 g), banana peel (6.02 g), orange peel (5.97 g), potato solid waste (3 to 5 g), carrot pomace (10.06 g), tomato solid waste (17 to 22 g), cabbage leaves (20.4 g), and pea pods, shell, and peel (20.2 g) per 100 g. Citrus peels have a 2.5–10.0% protein concentration, according to the literature [98].

2.2.5. Organic Acids

Important biomolecules named organic acids are employed in the chemical, cosmetic, and food sectors. Citrus fruits like oranges and lemons contain citric acid. Fruits like tamarinds and grapes contain tartaric acid. Citrus fruits contain ascorbic acid as one source of vitamin C. Lactic acid and citric acid serve important roles in the food and pharmaceutical industries. Fermentation employing a variety of molds, yeasts, and bacteria can produce citric acid. However, *Aspergillus niger* continues to be a preferred mold species for the production of citric acid in industries [99]. As a substrate material, *Aspergillus niger* has also been used to produce up to 80% of citric acid from apple pomace [100]. Citric acid has also been produced from the waste of pineapple, mandarins, and mixed fruits, yielding 51.4%, 50%, and 46.5%, respectively [101].

A possible method to restore bioactive ingredients (fiber and phenolic compounds) into the food processing chain is to obtain them from agro-industrial by-products. As a result, it may be possible to create products that significantly improve the health of their consumers. In this way, adjusting the composition and functioning of food can enhance both their applicability and quality.

3. Approaches in the Application of Agri-Food By-Products in the Food Industry

3.1. Incorporation of By-Products into Various Food Products, Such as Bakery Goods, Meat Products, and Beverages

During the industrial food processing of agri-food products, enormous quantities of waste are produced, causing significant environmental contamination. Agri-food by-products can play important roles even though they are typically used as animal feed, compost, or thrown away. Adding value to agri-food by-products makes them more desirable and increases their economic value. This is because numerous studies over the past ten years have demonstrated that they are sources of bioactive compounds like phenolic compounds, antioxidants, dietary fiber, carotenoids, natural pigments, and protein, among others. Therefore, agri-food by-products can be utilized to create novel, scalable, and nutritionally significant functional foods. These functional foods include beverages, morning cereals, dairy products, meat products, bakery goods, and sweets (Table 1) [102,103].

Table 1. Nutritional improvement in products with the addition of agri-food by-products.

Industry	Product	Incorporated Agri-Food By-Product	Nutritional Value	References
Bakery	Bread	Mango peel powder Green banana powder Pea powder Chickpea powder Banana peel powder	Increased dietary fiber and carotenoid content Increased polyphenol content and antioxidant properties Increased protein, dietary fiber, mineral, antioxidant activity and β-carotene contents Increased protein, resistant starch and dietary fiber content	Srivastava et al. [104] Ajila et al. [105] Martins et al. [106] Meral et al. [107]
	Cookies	Watermelon rind powder	Increased dietary fiber Decreased glycemic index Increased phenolic content and the antioxidant activity	Hussain et al. [108]
	Muffins	Orange bagasse Apple skin powder Sour cherry pomace Strawberry, raspberry pomace Goji berry by-product	Increased dietary fiber Increased antioxidant capacity Increased total phenolic content Decreased glycemic index Increase satiety Regulate long-term energy balance	Romero-Lopez et al. [109] Rupasinghe et al. [110] Ramírez-Maganda et al. [111] Bajerska et al. [112]
	Snack	Date fruit paste Figs fruit paste	Increased protein Increased dietary fiber Rich in thiamin, Ca, Mg, Zn	Ibrahim et al. [102]
	Cake	Potato peel powder Apple, orange, and carrot pomace	Increased protein content Increased dietary fiber content Increased fiber content Increased viscosity Increased fiber, protein, carbohydrates, and sensory acceptability Increased phenolic compounds and antioxidant capacity Increased total anthocyanins	Jeddou et al. [113] Kirbas et al. [114]
	Biscuits	Finger millet seed coat matter Legume flour (chickpea flour, pigeon pea, mung bean flour and cowpea flour) Apple pomace Grape pomace Apple, melon by-products	Increased protein, dietary fiber and calcium contents Increased fiber and phenolic compounds Decreased dialyzed glucose Increased fiber, phenolic compounds and antioxidant capacity Increased anthocyanins, phenolic and antioxidant capacity Increased fiber content	Krishnan et al. [115] Alongi et al. [116] Colantuono et al. [117] Theagarajan et al. [118] de Toledo et al. [119]

Table 1. *Cont.*

Industry	Product	Incorporated Agri-Food By-Product	Nutritional Value	References
Dairy	Dairy beverage	Olive vegetable water	Increased antioxidant activity Source of phenols	Servili et al. [120]
	Fermented milk	Apple pomace Wine pomace extract Grape marc flour Wine pomace extract and flour	Source of protein Probiotic protection Texturizing agent Source of fiber Source of phenols Increased antioxidant capacity Colorant agent	Issar et al. [121] Aliakbarian et al. [122]
	Yogurt	Grape seed extract Grape skin flour	Texturizing agent Increased phenols content Colorant agent Yogurt's syneresis level was considerably reduced Maintained textural and gelling formation	Chouchouli et al. [123] Marchiani et al. [124]
	Cheese	Peer/apple stones Orange by-products Pomegranate peel Tomato peel Grape seed Grape pomace Wine pomace, skin and seed extract	Increased phenols content Probiotic protection Texturizing agent Increased antioxidant capacity Increased antimicrobial capacity	Lucera et al. [125] Shan et al. [126] Da Silva et al. [127]
	Butter	Tomato peel	Increased antioxidant capacity	Abid et al. [128]
	Ice cream	Pomegranate peel	Texturizing agent Increased phenols content Increased antioxidant capacity Colorant agent	Cam et al. [129]
Meat	Chicken meat Patties Chickens thigh	Mosambi peel powder	Increased antioxidant capacity Anti-bacterial agent Increased microflora	Younis et al. [130] Gibson [131]
	Pork ground Meatballs Sausages	Tomato peel Grape seed	Increased antioxidant capacity	Shahidi [132]
	Shrimp Tuna	Pomegranate peel	Increased antioxidant capacity Anti-bacterial agent Enhanced meat flavor and color	Tekgül and Baysal [133]
	Beef meatballs, Sausages	Pomegranate peel Orange peel	Increased antioxidant capacity Anti-bacterial agent	Ergezer [134]
	Lamb meat Patties	Tomato pomace Grape pomace Olive pomace Tomato pamace Pomegranate pomace	Increased antioxidants Anti-bacterial agent	Andrés et al. [135] Bryant and Barnett [136]
Beverage	Apple juice	Pomegranate peel	Increased antioxidant capacity Anti-bacterial agent Enhanced juice flavor and color	Amofa-Diatuo et al. [137]
	Carrot juice	Orange pulp and peel	Increased antioxidant capacity	Wedamulla et al. [138]

3.2. Technological Applications of Food By-Products in Bakery Formulations

Adding functional food ingredients to bakery items would be a great method to satisfy consumer demand while keeping the products' high level of physical, chemical, and organoleptic quality and improving their nutritional worth. White wheat flour is typically the principal component used in the creation of bakery products, a food category with a large global consumption rate. White flour has a high nutritional value but little antioxidant activity. It is a very common practice to add fruit and vegetable by-products to bakery goods including bread, snacks, and biscuits in order to increase their functional features. It is also well recognized that several fruit and vegetable by-products, including carrot peels, beetroot, raspberry, and cranberry pomace, can be used to boost the phenolic and dietary fiber content of baked goods [139–141].

Up to 10% of the wheat, maize, and waste grain composite flour bread was improved by Ginindza et al. [142]. The exact volume of the bread reduced as the amount of spent grain rose, but the volume and density increased. As the amount of spent grain added grew, so did the amount of fiber, protein, and ash. Fruit-based flours, like those manufactured from grapes, can be used as an alternative because they are thought to be a good source of fiber and nutrients. Because they can alter or improve the sensory and nutritional qualities of food products, consumers have come to connect fruit residues with healthful products [143,144].

Ungureanu et al. [145] examined amounts of grape skin flour above 3% in a study on pasta and noted more cooking loss, decreased brightness, increased red color, decreased dough elasticity, harder dough after cooking, and rougher surface. Gelatinized starch leaching, which accounts for the majority of cooking losses, is more prominent in gluten-free products because of the absence of the gluten network.

3.3. Technological Applications of Food By-Products in Dairy Formulations

According to the most recent Food Balance Sheets (FAOSTAT), compared to the other commodity groups—cereals, roots, and tubers; oilseeds and pulses; meat, fish, and shellfish; and dairy products—fruit and vegetables had the greatest levels of food losses along the food chain. The use of fruit and vegetable by-products as innovative ingredients in the manufacture of foods, particularly dairy products, consequently attracted more attention. This emphasis may be explained by a number of elements, including their environmental impact, the probable presence of phytochemicals that are health-promoting, and the fact that plant-derived by-products and losses primarily occur before family consumption, leaving them still available for reuse [146].

The impact of by-product addition on the physicochemical and sensory characteristics of spreadable cheese was examined in the study of Lucera et al. [125]. The findings showed that broccoli, artichokes, maize bran, and cheese samples with red and white wine grape pomace added produced the best outcomes from a nutritional standpoint. In general, when compared to the control sample, the addition of vegetable flour to cheese considerably enhanced the total phenolic content and flavonoids. Spreadable cheese could be enhanced technologically by adding red and white wine grape pomace to boost antioxidant components without sacrificing the sensory qualities.

As grape seed extracts were successfully used to prevent lipid oxidation during storage, grape pomace was found to delay oxidation of lipids in yogurt in an investigation by Marchiani et al. [147]. In addition, the addition of grape pomace may be utilized to increase the shelf life of dairy products by improving their capacity to be stored. It has been shown that using grape pomace can significantly boost the antioxidant activity and total phenolic content, which are absent from dairy products. In order to boost the polyphenol content of semi-hard and hard cheeses, grape pomace powder from Chardonnay was utilized. The results from Gaglio et al. [148] indicated that depending on the type of extract supplied, effects on pH that may increase acidity require special consideration. However, grape pomace can be used as a functional ingredient to boost cheese's total content of phenolic compounds and its capacity to neutralize free radicals. Additionally, the inclusion of grape pomace can boost protein levels and secondary lipid oxidation while lowering the cheese's fat content.

3.4. Technological Applications of Food By-Products in Meat Products

In their study of the oxidative stability of sausages with additional natural pigments and storage under refrigeration, Mercadante et al. [149] found that adding lycopene (10%) resulted in considerable decreases in redness but had no antioxidant impact.

Huda et al. [150] tried to create high fiber functional mutton nuggets that included apple pomace as well as to assess how the apple pomace affected the physico-chemical, textural, and sensory characteristics of the mutton nuggets. The crude fiber content of the control was discovered to be lower than that of the nuggets made with 5%, 10%, and 15% apple pomace, and it was discovered to considerably rise with the addition of more apple pomace. According to the textural characteristics, the goods' hardness decreased when apple pomace was added, but only slightly affected the products' springiness, cohesiveness, chewiness, and gumminess. In a study using grape flour and no heat treatment, Tremlova et al. [151] produced vegetarian sausages to see how they would turn out. They assessed how adding grape flour affected the chemical, physical, and sensory characteristics of this vegan sausage. Grape flour addition to vegan sausages increased antioxidant capacity and increased polyphenol content.

3.5. Technological Applications of Food By-Products in the Beverage Industry

The most advantageous aspect of beverages is that they make excellent carriers for delivering and incorporating nutrients and bioactive chemicals into the body. Since beverages are one of the best methods to provide our bodies the nutrients and bioactive substances they need, plant-based fermented beverages increased in popularity and quality in recent years [152]. It is generally recognized that by-products of the wine industry, notably wine pomace, can be utilized to prolong the shelf life of foods by inhibiting oxidative deterioration and limiting the development of spoiler bacteria [153].

In the brewing industry, the addition of white grape pomace from the Solaris variety raises the concentration of several volatile ingredients, such as ethyl decanoate or ethyl dodecanoate, which affects the sensory qualities of the beer. White grape pomace used to make beer has higher levels of phenolic compounds and antioxidant qualities. Fruit raised the concentration of organic acids including succinic, tartaric, and malic while decreasing the concentration of sugars in the beer [154]. Additionally, different authors like Pérez-Bibbins et al. [155] demonstrated that beers made with white grape pomace contain less of the harmful substance acetaldehyde.

4. Environmental and Economic Benefits of Reducing Food Waste and Utilizing Agri-Food By-Products

According to FAO's report published in 2021, 828 million people were affected by hunger globally, and 3.1 billion were unable to afford a healthy diet. According to estimates, approximately 17% of global food production is lost in the supply chain, and 61% is wasted in households, 26% in food service, and 13% in retail [156]. Unsustainable agri-food systems degrade agricultural land, contribute to greenhouse gas emissions, loss of biodiversity, and consume groundwater. Reducing food loss and waste can transform agri-food systems, increase food availability, contribute to food security, healthy diets, and build resilience. This also serves as a climate strategy, by reducing greenhouse gas emissions and helping countries and businesses raise climate ambition while conserving ecosystems and natural resources [157].

Taking into consideration that the global population is projected to reach approximately 8.5 billion by 2030 [156], there is an urgent need for innovations to increase agricultural productivity while decreasing food waste [158]. According to the numbers provided by *The World Counts*, over one-third of the world's food was wasted in 2022, and nearly 98 million tons of the world's food has been wasted in 2023 up until the end of June. Also, the direct economic implications of food waste amount to around $750 billion each year, excluding fish and seafood [159].

Food waste incorporates nutrient-rich elements, such as lipids, proteins, polysaccharides, and metal ions, that can be recycled in certain processes to create products with added-value. In addition, food waste can be converted into biohydrogen, biogas, and biodiesel, which may serve as a substitute for nonrenewable fuel, thereby lowering reliance on fossil fuels. Several investigations demonstrated that, in experimental conditions, the synthesis of biochemicals from food waste is comparable to that from pure carbon sources [160].

According to Torres et al. [8], food waste is an important raw material with nutraceutical, nutritional, and medicinal benefits, which makes it an attractive ingredient for food formulations in developing nations. Individually extracted biomolecules such as vitamins, minerals, lipids, proteins, starch, antioxidants, and fibers can be used as nutritional ingredients. Functional food combined with bioactive ingredients offers additional nutritional benefits in addition to their nutritional effects. They support human health and protect against chronic conditions such as obesity, hypertension, diabetes, and cancer [161]. Innovative technologies of extraction such as ultrasound, microwave, pressurized liquid extraction, and enzyme-assisted extraction are used to extract these compounds, thereby minimizing environmental impacts, and enhancing the final product's qualities [161,162].

The juice companies, which is the main producer of fruit and vegetable by-products with bioactive potential, enables the transformation of these matrices into useful and unique products that have positive health effects. Thus, their potential allows for the development of personalized, functional products with health benefits [163].

Reducing food waste and utilizing by-products improves resource efficiency in food production. This reduces the misallocation of resources, such as land, water, energy, and labor. Minimizing waste optimizes resources used in food production, reducing pressure on ecosystems, and promoting sustainable resource management. Proper management of by-products, such as composting and recycling, leads to more sustainable agricultural practices, preserving biodiversity and protecting ecosystems. Reducing food waste and optimizing the use of by-products can significantly reduce economic costs and improve food security. By minimizing losses for farmers, reducing disposal costs for businesses and saving consumer's money, these by-products can be redirected to more uses that are productive, benefiting individuals, businesses, and the economy. This approach also presents opportunities for innovation and market development, fostering the growth of industries focused on waste reduction, recovery, and recycling. These emerging sectors contribute to job creation, economic growth, and increased competitiveness in the market. By maximizing the value derived from by-products, food production can be optimized, reducing the need for additional resources, and increasing overall food availability.

From the perspective of environmental protection, it is crucial to safely dispose of processing waste in order to reduce the amount of it, for example, by using integrated strategies to fully utilize the by-product in order to recover valuable by-products and/or ingredients. The high-added-value compounds may be used as nutraceuticals or food additives after recovery. The approach that waste is now managed is not only expensive, but it also harms the ecosystem. A strategy for the environmentally responsible use of by-products with the potential to be turned into food products must be developed. The development of novel, appealing products with bioactive qualities and a reduction in the impact of accumulation on the environment may be the goals of using agro-industrial wastes to produce bioextracts from the by-products [25].

5. Future Directions and Challenges

The use of by-products in the agri-food sector rapidly gained attention as a result of its potential to reduce waste, improve sustainability, as well as create additional value by adding to agricultural process efficiency. By adopting a circular economy approach, by-product utilization in agriculture will flourish. Rather than treating by-products as wastes, there is a growing trend to integrate them into the production process. Optimizing resource usage and minimizing waste contributes to sustainability and efficiency [164].

To account for food waste, the food industry generates tons of by-products when processing food each year. Fruit and vegetable by-products, which might develop during the pre- and post-harvesting, preparation, and processing of fruit and vegetables, make up the majority of the components. By-products contain phytochemical substances that have known anti-inflammatory and anti-oxidant effects. Food waste is typically converted into animal feed, biogas, biomaterials, platform chemicals, biofuels, and bio-fertilizers [165]. However, over time, they have been used in a number of industrial industries (cosmetic, pharmaceutical, and food) because of the immense potential of their active compounds. The objective in the food sector was to re-introduce by-products as raw materials, to create new products with health benefits, to improve food preservation, or to create active packaging (Figure 2) [166].

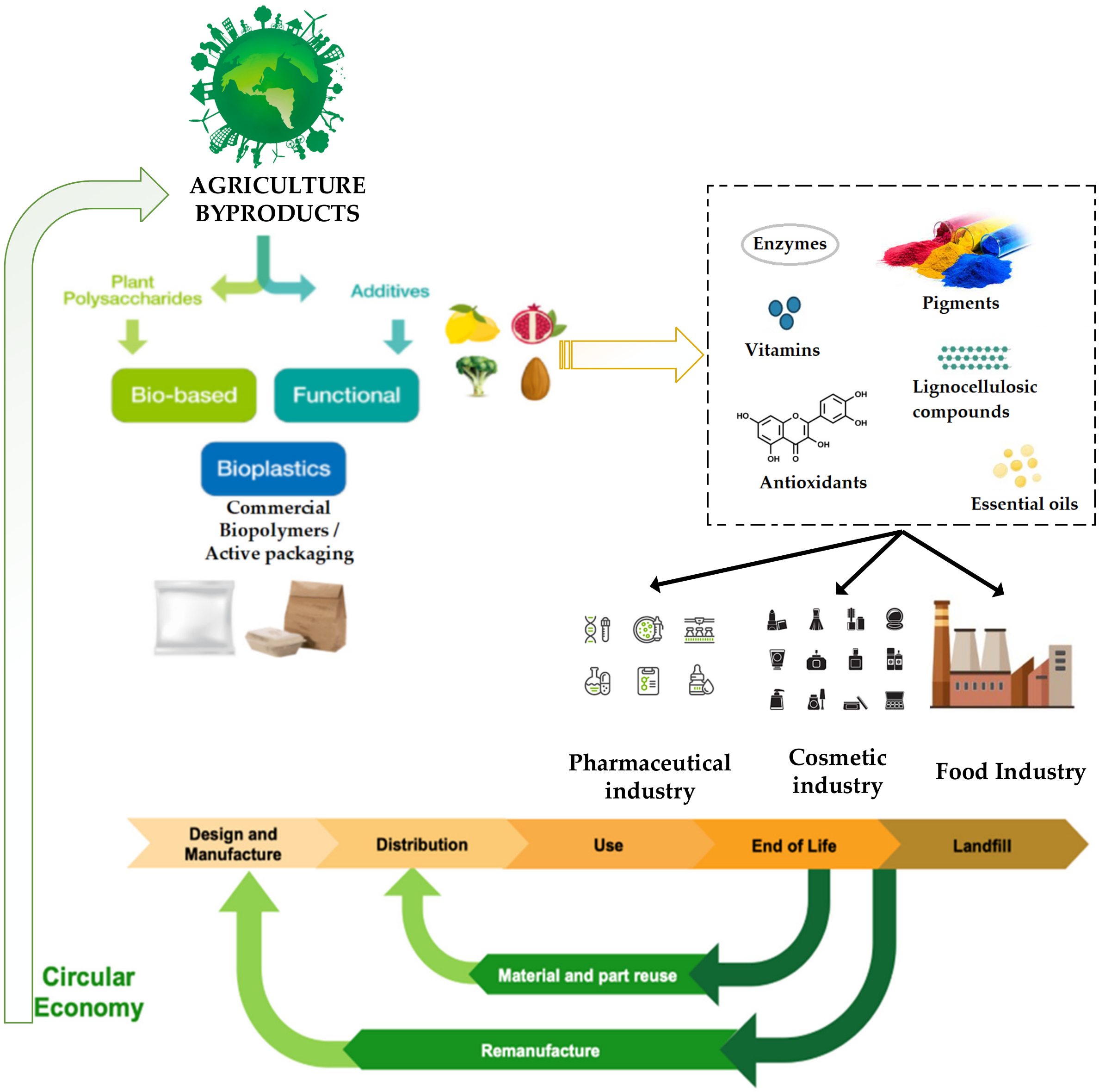

Figure 2. General scheme of valorization of agri-food by-products in the circular economy.

In addition to their nutritional value, by-products can also contain bioactive compounds and nutrients that can be extracted and used for a variety of purposes. The future research and development efforts will be focused on identifying and optimizing extraction processes in order to maximize these by-products' functional and nutritional value. There are several approaches to this problem, including using new enzymes, fermenting processes, and a number of biotechnological techniques. Numerous studies document the use of these by-products. As sources of bioactive agents to create films and coatings with antimicrobial and/or antioxidant abilities, as ingredients in various types of food that improve nutritional value, as natural preservatives to preserve food quality, and as sources of bioactive agents for these purposes [167].

The waste of food is considered a raw material that is nutritionally, functionally, and nutraceutically valuable. These raw materials can be used to make a wide variety of food formulations, making them a potential solution to issues regarding economic, social, and environmental sustainability. This can include their use as food ingredients, or as protein, lipids, vitamins, fiber, starch, minerals, and antioxidants, or as supplements. The food by-products contain additional biomolecules that can be chemically or physically extracted and utilized as functional and nutritive components. The application of the unitary drying operation is required to minimize microbial hazards and maintain the physicochemical and microbiological stability of biomaterials during the valorization of these food wastes. Governments should, therefore, promote the development of the technology and infrastructure necessary to enable the use of food by-products and wastes in production and storage regions. On the other hand, removing additional hazards like those posed by hazardous materials and antinutritional elements should also be taken into account [8].

It is well known that the agri-food sector faces a number of significant environmental challenges related to waste management and environmental impact. It has been shown that by using by-products, the industry can reduce waste generation, lower greenhouse gas emissions, and conserve resources, therefore minimizing its ecological footprint. As part of future efforts, we will be focusing on improving waste management systems, improving waste valorizing technologies, and tackling regulatory and logistical issues. There are a number of factors that should be considered when integrating by-products into the agricultural and food industries, including consumer acceptance and marketability. The perceptions of consumers, their taste preferences, and product labeling play an extremely important role in determining how successful by-product-based foods are in the market [168].

The sensory quality of the food materials and acceptance by consumers is another important restriction on the use of food wastes/by-products as functional food ingredients for the design and development of new food products. Compared to their usage as biofuel in the industry, food wastes and by-products are rarely used as useful components in industrially produced food. Therefore, research that is more thorough is required to improve the quality and consumer acceptance of novel functional foods. Additionally, the companies ought to make an effort to valorize their food by-products and wastes by incorporating them into new products. To reintegrate the wastes of their products to the original food on an industrial scale, for instance, changes in the processing processes and designs may be taken into consideration (to make tomato paste or sauce, tomato skin and seeds can be processed). On the other hand, it is likely that the intermediary enterprises (waste brokers) will multiply in the future, which will be advantageous from the standpoint of waste valorization. Waste brokers are organizations that gather trash and direct it to certain locations for processing into novel products or components. However, a look at the future will involve the development of innovative processing techniques, the creation of appealing and nutritious food products derived from by-products, and the implementation of effective marketing strategies to enhance consumer acceptance [8].

Among the stakeholders that can realize the full potential of using by-products within the agricultural food industry is collaboration and policy support, which includes farmers, processors, researchers, policymakers, and consumers. It is possible for governments and regulatory bodies to provide support by providing policies and incentives that encourage the utilization of by-products encourage the advancement of research and development, and set quality and safety standards. The by-products in the agricultural industry hold great potential as a way to address sustainability challenges, reduce waste, and create value for the future in the agri-food sector. There will still be challenges to overcome, however, and this will require ongoing research, innovation, collaboration, and supporting policies in order to overcome these challenges [167].

6. Conclusions

A significant amount of food industry by-products can be utilized as raw materials in the development of functional foods because they serve as valuable raw materials. Due to their disease-curing properties, functional foods have been steadily increasing in popularity for years. The research that is now available makes it clear that agri-food by-products offer a variety of opportunities for the isolation of natural bioactive compounds with potential uses in the food industry. Food by-products can be employed as proteins, lipids, fibers, vitamins, starches, antioxidants, minerals, or as food ingredients. Food industry by-products can be effectively utilized to decrease negative costs, reduce environmental pollution, and demonstrate sustainability, which, in turn, influences the country's economy directly. This can help reduce the negative costs associated with the food industry. Consequently, the food industry is becoming an integral part of the zero-waste society and the nation.

Food by-products will also help to boost new markets in functional foods, by serving as functional food ingredients. In food science and technology, one of the biggest challenges is finding new functional food ingredients from natural sources. In order to make valuable food by-products and increase profitability, science and innovation should be used.

Food by-products could be used to create novel functional food products or ingredients because of all the evidence that has already been reported highlighting their qualities and richness in bioactive molecules. This is the main advantage for the industries for their transformation into valuable products within the circular bioeconomy framework. Therefore, more thorough research on the development of novel functional foods is required in order to increase their quality and acceptance among consumers.

As was the case at the start of the twenty-first century, we are currently in a time of transition toward something new, more diverse, and centered on the promotion of green technologies and the circular bioeconomy in order to harness these natural resources for human welfare and to contribute to sustainable development.

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