

Review

Food Additives from Fruit and Vegetable By-Products and Bio-Residues: A Comprehensive Review Focused on Sustainability

Jonata M. Ueda , Mariana C. Pedrosa , Sandrina A. Heleno ^{*} , Márcio Carocho , Isabel C. F. R. Ferreira 
and Lillian Barros ^{*} 

Centro de Investigação da Montanha (CIMO), Instituto Politécnico de Bragança, Campus de Santa Apolónia, 5300-253 Bragança, Portugal; massaoueda@hotmail.com (J.M.U.); marianapedrosa@ipb.pt (M.C.P.); mcarocho@ipb.pt (M.C.); iferreira@ipb.pt (I.C.F.R.F.)

^{*} Correspondence: sheleno@ipb.pt (S.A.H.); lillian@ipb.pt (L.B.); Tel.: +351-273-303-285 (S.A.H.); +351-273-303-219 (L.B.)

Abstract: Food waste is one of the fundamental issues when it comes to environmental impacts, and this type of waste results in the food's loss itself, but also that of water, energy, fertilizers, and other resources used for its production. Many vegetable parts are removed from the final product before reaching retail (peels, roots, and seeds), and these raw materials are rich sources of highly valuable molecules such as phytochemicals, minerals, vitamins, and other compounds with health benefits (prevention of several diseases, improvement of the immune system, regulating gastrointestinal transit, and others). Therefore, substantial efforts have been made to find technological solutions to avoid food waste, namely through its reuse in the food chain, thus promoting the circular economy and sustainability. This review focuses on the biggest wastes generated by the food industry, the most common destinations, and case studies applying these by-products or biowaste in the food industry.

Keywords: food additives; vegetables; fruits; biowaste; by-products; sustainability



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1. Introduction

Environmental problems, economic losses, inefficient use of resources (land, energy, water, chemicals, labor) are consequences of food loss and waste [1,2]. About a third of the world's food production is lost or wasted per year, and around 22% of this loss is residue from fruits and vegetables (FV) [3,4], resulting in approximately \$490 billion in losses per year. From the environmental point of view, it represents 8% of greenhouse gas emissions, 23% of fertilizer consumption, and 25% of fresh water used in agriculture and the use of arable land [5]. Food waste and loss was identified as one priority for the application of the European Circular Economic Strategy by the European Commission, in which food issues, such as safety and waste management, are among the major problems of the century [6].

In food waste processing, effluents and by-products are produced, products that, if treated incorrectly, can further negatively aggravate environmental impacts. Thus, the need for innovative solutions for the reuse of waste and by-products becomes a mandatory target of research [7]. The by-products and FV residues have the potential to be reused in secondary processes as a source of valuable compounds (oils, lipids, proteins, fibers, and phenolic and other bioactive compounds) [8].

Therefore, this review aims to describe the ways in which by-products are discarded and the potential reuse of residues from fruits and vegetables generated at different stages of the supply chain, and reports the main existing potential solutions to valorize the reuse of these raw materials.

2. Generation of Fruit and Vegetable Waste

2.1. Food Waste Definition

According to Directive 2008/98/EC of the European Parliament and of the Council, waste is defined as “any substance or objects that the holder disposes of or has the intention or obligation to dispose of”, and biowaste as “waste from biodegradable garden, food and kitchen residues from homes, restaurants, catering and retail units and similar residues from food processing units” [9]. In this review, biowaste will be portrayed as waste.

The absence of a definition of loss and food waste commonly accepted in the literature is an aspect that provides diversity in analyses and estimates. Consequently, it makes it difficult to unify the study of food loss and waste along the supply chain. Data from different sources can contain great heterogeneity and present a relevant range of values [5,10,11]. The Food and Agriculture Organization of the United Nations (FAO) understands that the negative variation in the quality and quantity of food is a loss or waste, and differentiates between the definition of food loss and food waste. Therefore, FAO considers: “food loss, as occurring along the food supply chain (harvest/slaughter/capture) until, but not including the retail level. Food waste, on the other hand, occurring in retail and consumption level (. . .), inedible parts are not considered as loss or food waste” [4].

In contrast, Food Use for Social Innovation by Optimizing Waste Prevention Strategies (FUSIONS) presents a broader definition of food waste: “is any food or inedible part of food removed from the supply chain to be recovered or disposed of” [12]. In comparison, the FUSIONS definition joins the FAO definition of food loss and waste, and adds inedible parts of food such as peels, logs, and others [3,12]. In this article, the concept used will be in accordance with FUSIONS due to the greater scope of the term.

The waste generated in the supply chain can be treated and converted into products with added value [5]. With vegetables, some by-products are peels, seeds, stems, leaves, roots, and pieces of food that derive from processing [13]. As wasted products have valuable compounds which can be extracted and used in different products, some researchers use the term “by-product” or “co-product” to identify wasted food, which have these molecules [5,14,15].

2.2. Waste in the Food Supply Chain

There are many indications that fruits and vegetables play a key role in the human diet. The presence of magnesium in these foods, for example, is associated with a reduced risk of type 2 diabetes [16]. Likewise, the intake of phenolic acids, carotenoids, and vitamin C are highly associated with the prevention of overall cancer and cardiovascular diseases due to the reduction of oxidative stress [17]. Furthermore, vegetables influence other aspects of the human body's systems, such as improved appetite, enhanced flavor, and improved digestion. The advantages mentioned above are mainly explained by the composition of these foods, with many vitamins, fibers, minerals, and phytochemicals and a low caloric value (proteins and carbohydrates) [13,18].

The per capita consumption of vegetables in the world is 199 g/day, half than the recommendations of The World Health Organization (WHO) of 400 g/day and defined as the ideal content for significant health benefits. Data show Asia is the major consumer of vegetables, followed by Africa, North America, Oceania, Latin America and, finally, Europe. Regarding food waste, the continents follow the reverse order. Europe, North America, and Oceania, where the income is highest, are the most wasteful, followed by Asia, Africa, and Latin America, continents with limited sources of food [13]. India is one of the largest fruits and vegetable producers in the world, and over 30% of its production is lost due to difficulties in transport and storage that cause physical changes in food [19].

Agricultural and agro-industrial activity produce a large portion of waste and by-products [20]. The residues and by-products of fruits and vegetables (RBFV) occur mainly due to the fruits and vegetables being perishable and fragile to mechanical damages during processing. Moreover, there is also an unsuitable appearance, unwanted microorganisms in FV, and unnecessary parts in the final product [3].

Each stage of the supply chain (production, processing, packaging, handling, and transportation) contributes to the generation of these RBFV. In the first stage of the supply chain (production), there is a loss in the production itself, caused by mechanical damage to food, products left on the ground, climatic factors, insect and pest infestations, and deterioration of the harvest. Post-harvest, it is caused by improper handling and management, which makes it difficult to handle, store and transport the fresh product, in addition to deterioration over time [21]. In the intermediate stages of processing and distribution, the losses of the former are caused by the degradation and deterioration of the industrial process of transformation and the elimination of foods that are not suitable for processing. The causes of the distribution are due to low infrastructure, both in storing and packaging. In the last stage of the supply chain (consumption), the loss occurs due to the deterioration and non-consumption of the purchased food by the consumer, which is subsequently discarded in dumpsters along with other waste. In all stages of the chain, the qualitative and quantitative loss is present [4,11,13,22].

Waste in the consumption stage represents only 10% in developing countries, in which the harvesting and processing are the biggest stages of loss due to the lack of adequate infrastructures for storage and transport. In developed countries, due to stricter safety and quality standards, the greatest losses are in the harvest and consumption steps [5]. Figure 1 shows data regarding the loss of FV from world regions during each stage of the supply chain.

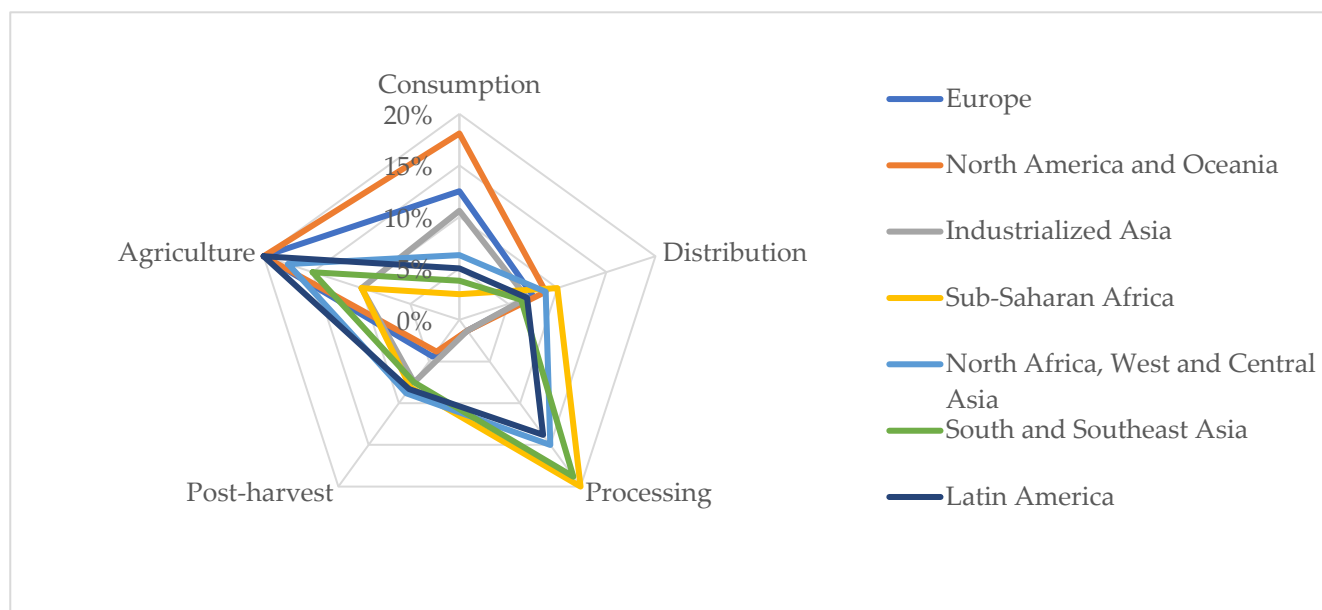


Figure 1. Fruits and vegetables loss during the supply chain in different regions.

Within the FV sector, the juice, vegetable, oil, potato starch, sugar and canned FV industries are among the main residue generators. FAO data estimate that 88 million tons of losses are generated by the European Union, with a growing trend. In North America, the value is almost double, about 170 million tons [5]. In the economic aspect, 750 billion dollars/year are lost in food waste [3]. Figure 2 exemplifies the estimated post-harvest loss of FV from other countries [22].

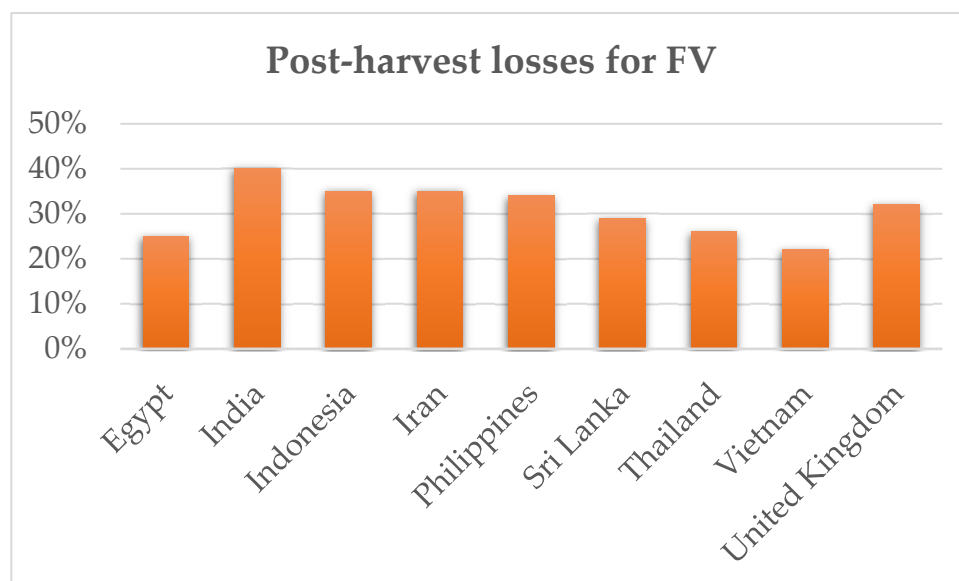


Figure 2. Fruits and vegetables loss post-harvest for other countries.

Several reports show that 38% of the used raw material in weight is equivalent to by-products, namely leaves, seeds, stems, branches, peels, waste from trim, pulps and bagasse [23,24]. Besides that, the amount of waste may be influenced by the countries' infrastructure and cultural issues. Worldwide data referring to the quantity and type of by-products generated are few, mainly due to a difference in definitions and difficulty in collecting information in some stages along the supply chain [13].

2.3. Most-Representative Fruits and Vegetables Generating Waste

In Figure 3, the main by-products from different foods are shown, and Table 1 summarizes the data found in the literature about the annual production of vegetables and fruits, the percentage and amount of by-products only, as well as their destination.

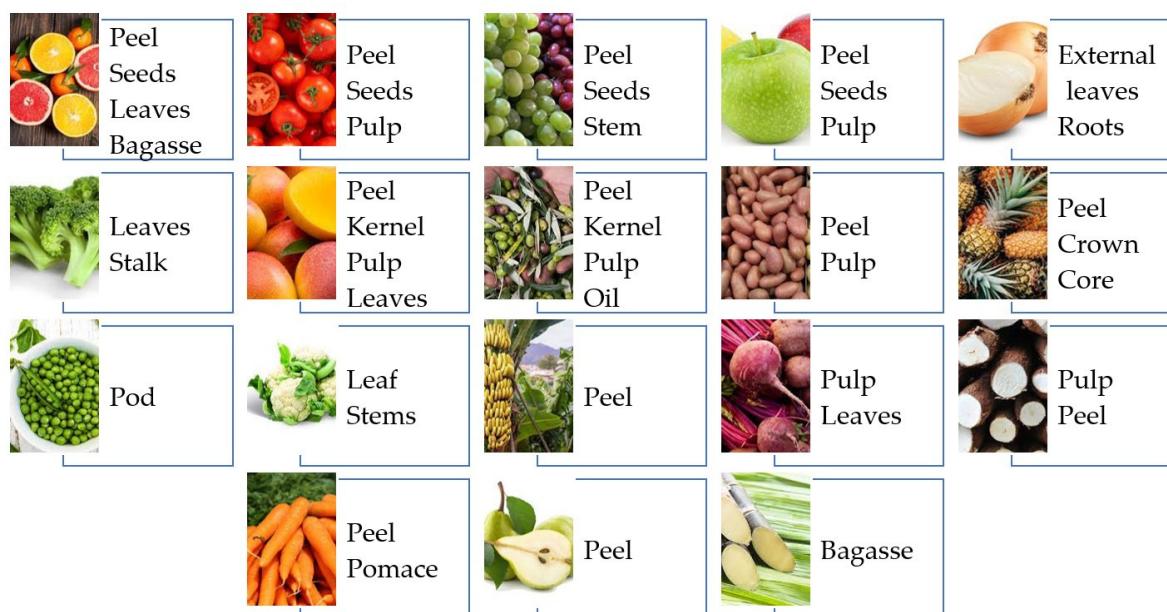


Figure 3. Main by-products of fruits and vegetables.

Table 1. Production of fruits and vegetables and respective by-products generated.

	Amount of FV Produced (Million Tons)	Percentage of Waste and By-Product (%)	By-Products or Bio-Residues	Amount of By-Products or Bio-Residues (Million Tons)	Destination	References
Grape	70	20–40	Pomace	+10	Animal feed, composting, seed oil extraction, alcoholic drink production	[15,25]
Apple	69	25–35	Pomace	17–24	Fertilizer, animal feed, pectin extraction, seed oil extraction	[15,26,27]
Citrus fruits	110–115	50–65	Peel	+15	Deposition on land near the production site, animal feed, and burning	[28,29]
Potato	368	15–40	Peel	48–140	Landfill and animal feed	[15,26,30]
Tomato	146	3–7	Pomace	4.3–10.2	Animal feed	[15,26]
Banana	102	30–40	Peel	9	Incineration deposition in plantation areas, animal feed, biogas production	[15,20,31]
Mango	39	15–60	Peel	-	Untreated deposition, animal feed	[32–34]
Beet	228	-	Pulp	80	-	[26]
Onion	85.8	5–50	Peel	0.5	-	[32,35]
Olive	20	20	Olive endocarp	3.7	-	[26]
Pineapple	19–25	10–60	Pomace	8.7	-	[20,32]
Sugarcane	1949.3	30	Bagasse	584.8	Fuel to power the sugar mill	[36]
Pear	23	15–20	Leaves and pomace	3.5–4.6	Animal feed, incineration, landfill	[37]
Pea	13.5	-	Pod/hull	-	Incineration	[38]
Carrot	40	12%	Pomace and peel	4.8	-	[39,40]

2.3.1. Fruit Waste and By-Products

The main citrus fruits that have a global representation are orange (*Citrus sinensis* L.), lemon (*Citrus limon* L.), lime (*Citrus aurantiifolia* L.) and mandarin (*Citrus reticulata* L.), with an annual production of approximately 109.1 million tons. The peels, internal tissue and seeds are by-products generated by the industry. About 50% of the fruit becomes by-products during processing, and about 15 million tons of peel waste are generated per year [28,29].

Grape (*Vitis* sp.) bagasse is another residue composed of the peels, seeds and stems of the fruit, generated in the production of wine (about 80% of the total production of grapes) [15]. Furthermore, the by-products may come from the production of juices, jelly and raisins, but in smaller quantities [18].

Apple (*Malus domestica*) pomace, for instance, is a residue composed of the peels, seeds, stems and pulp of apples, produced by the fruit juice industry [15,27]. Mango (*Mangifera indica* L.) is one of the most important tropical fruits in the world, and the main by-products produced by mango are peels and seeds. This fruit can be consumed in juices, in jellies, frozen, dehydrated, concentrated, and in other forms [15,34].

Olive (*Olea europaea*) pomace is also a solid residue that contains peels, pulp, pieces of seeds and oil [41]. The pineapple (*Ananas comosus* L.) industry generates high amounts of waste, namely, skin, the crown, and the center of the fruit, that are discarded as low-value residues [42]. Banana, a widely consumed fruit, presents the peel as the main bio-residue, and only 12% of the plant is edible. This fruit is part of the Musaceae family and is identified as one of the most important fruits in the world [20].

Sugarcane production was estimated at 1949.3 million tons in 2019, Brazil being the largest producer, followed by India and China. The alcohol and sugar industries are the major users of this product and, consequently, the main producers of bagasse. Although bagasse corresponds to about 30% of the production and main by-product, other residues are generated, such as cane trash, molasses and press mud [36,43,44].

The pear (*Pyrus* spp.) is a fruit widely consumed worldwide, which had a production of 23 million tones in 2012. Furthermore, about 15–20% by mass are by-products (e.g.,

leaves and pomace) generated in the manufacture of pear derivatives, such as jams, puree and dried and fresh fruits [37,45].

2.3.2. Vegetable Waste and By-Products

Tomato (*Lycopersicon esculentum* L.), which is considered the second most important vegetable crop in the world [46], generates peels, seeds, and pulp as the main by-products [24]. The main tomato producers are China, India, the United States of America, Turkey, Egypt and Mexico. In the Asian continent, China loses 35% of its production after harvest, India 40%, and Turkey 20%. In the African continent, in which the major producers are Egypt, Nigeria and Tunisia, tomato production in 2012 was 17.94 million tons and production loss ranged from 20 to 30%. In Latin America, Mexico loses up to 20% of production, and Brazil 10% [13].

Another important food worldwide is potato (*Solanum tuberosum* L.), considered the most important vegetable crop in the world, and its most important by-product is the peel [46,47]. Chips and fries are the primary products of potato processing [14].

Onion (*Allium cepa* L.) is a crop of world importance, and its major producers are China, India and the United States. Onion losses in developed countries are found mainly in retail and consumption, varying from 5 to 30%. In developing countries, losses are around 50%, and are mostly from the beginning of the chain to retail [35].

Broccoli and cauliflower (*Brassica oleraceae* var. *italica*) produce the leaf and stem as by-products, in which about 37% of cauliflower is wasted along the production chain. An estimate of the production of broccoli and cauliflower showed that 50% of the waste could be used as animal feed, and the other half for bioconversion into new products [13].

Pea (*Pisum sativum* L.) is a leguminous plant with world-wide importance. In 2018, its production was around 13.5 million tones, with Canada, India, Russia and China being the main producing countries. The high protein content is a valuable feature for the industry and can be produced in wet or dry form. In processing, the pod is one of the main by-products that is usually rejected and burned [38,48].

Beetroot (*Beta vulgaris* L.) is a root vegetable from the Amaranthaceae family. Its main by-products are leaves, pulp and stems, which correspond to 15–30% of processing. They are typically discarded with no value added, such as with feed, fertilizer, or final disposal with no use whatsoever [49,50]. Another vegetable with a global impact is cassava (*Manihot esculenta* Crantz), the fifth most widely used starch and the third most consumed in tropical areas, with estimated production in 2019 of approximately 303 million tons [51,52]. The main residues generated are leaves, stems, peels, wastewater and starch bagasse. As for producing cassava starch, almost the same value that is produced is generated of bagasse, for example, 1 ton of starch can generate maybe more than 900 kg of bagasse [53,54].

Carrot (*Daucus carota* L.) had an estimated production of 40 million tons in 2018 and is considered one of the 10 most important vegetables globally. Moreover, it is a high source of β -carotene. Regarding the by-products, they are mostly pomace and peels. In juice manufactures, these residues can represent about 12% by weight of the biomass [39,40].

2.4. Destination of the Generated By-Products/Biowaste

The destination of the generated biowaste and by-products can occur in different ways. The most common and cheaper destinations for dumping are places close to the production site and in sanitary landfills, waste incineration, animal feed and soil fertilization [26,32]. Besides these, other methods employed are composting and anaerobic fermentation [55]. However, the legislation in each region can make it difficult to dispose of waste, given that vegetables can suffer deterioration and generate problems in product quality and safety [18]. If the residue is edible and is in a condition to be eaten, the redistribution of food should be prioritized, followed by its redistribution as animal feed. If it is not edible and cannot be consumed for any other reason, the use of new recovery methods and technologies is important, even to valorize these raw materials [3].

Besides leachate, landfill deposition generates methane (CH₄) and carbon dioxide (CO₂) due to microbial decomposition, which are harmful to the environment [5,20]. The anaerobic degradation of organic matter corresponds to the emission of 800 million tons of CO₂. North America, Europe and Asia are the main emitters of greenhouse gases in the atmosphere from landfills [56]. In Mexico, 44% of urban waste is fruits and vegetables disposed of in landfills and open dumps [57]. If properly disposed, the biogas produced in anaerobic degradation can generate energy and consequently valorize this waste, while also presenting potential to be used as a bio-fertilizer [58].

Regarding animal feeding, not all waste and by-products are eligible for animal feed since it is necessary to analyze the nutritional composition and possible presence of toxic compounds for the animals. Nevertheless, a low amount of water in the residue (less than 40% by mass) makes incineration viable. However, the incineration process releases highly toxic pollutants, while higher water contents favor the use of anaerobic fermentation [5,20,55]. Using landfills and incineration without energy harnessing are treatments that cause great environmental impacts and are not advantageous [3].

The disposal of FV residues and by-products using traditional methods, mentioned above, causes their devaluation. Waste recovery methods, such as the extraction of bioactive compounds and their conversion to generate biofuels and biomaterials, are strategies for a “cleaner” food production that are integrated with environment protection [5].

3. Valorization of By-Products/Biowaste

The “cleaner” food production that is integrated with the environment is based on the principle that losses must be reduced and reused/recycled, with the aim at valorizing these by-products and the waste produced, as well as executing innovative processes and developing products that work collaboratively with the environment, always aiming for quality, safety and efficiency [5,56].

Biorefinery comprises transforming the biomass from different sources into heat, energy and chemical compounds with added value. However, this process still presents high costs from an economic point of view. Variables such as composition, purity, stage of the supply chain, transportation and storage are aspects that must be studied and influence the final value of these products [56].

Economically, the transformation into energy generates less value (60–150 €/ton), together with animal feed (70–200 €/ton), followed by the use of biofuels (200–400 €/ton). The most profitable would be the transformation into bio-chemicals (1000 €/ton); however, the application of processes (extraction, purification, transport and storage) on a large scale are still a challenge for the industry [5].

RBFV are natural sources of carbohydrates, bioactive compounds, minerals and dietary fibers [24,32]. The interest in the valorization of these RBFV is increasing exponentially, for instance, through the use of food additives, functional foods, nutraceuticals, pharmaceuticals and others. Furthermore, there is a tendency to substitute synthetic components for natural ones, as they present less or no toxicity and, consequently, the development of a sustainable circular economy with less environmental impacts [21,23].

As these co-products and bio-residues are considered a waste for the food industry, they have a low economic value. This characteristic, added to the fact that many of these wastes have high biological activity and can be used to obtain bioactive compounds, make them an interesting alternative for several applications [59].

In the United States, in 2002, a US patent application 2002/0187239 proposed using nutritional constituents derived from by-products generated in the processing of coffee (coffee husk and undesirable parts); macadamia (internal and external husk); mango (peel and seed); yam (peel and seed); and papaya (peel and seed), which shows the opportunity to use secondary processes for the extraction of bioactive compounds. The extract from passion fruit peels, which has showed antioxidant and anti-inflammatory activity, besides other beneficial health effects, is another example of a patented by-product [32].

According to Ayala-Zavala et al. (2018), an increase in the amount of flavonoids, phenolic content, and consequently the antioxidant capacity in orange slices was verified with the addition of orange seed extract [3]. There is also the use of a tangerine extract from the leaves and peels of the fruit as a Kraft paper coating, showing improvement against oxidation reactions, improvement in protection against moisture and the potential for application as packaging and coating agents for foods to extend the shelf life [60].

The application of FV by-products in cereal is also used, such as olive, grape and carrot bagasse to enrich the phenolic compounds content in pasta, as well as tomato peel and apple bagasse to enrich dairy products, namely, cheese and yogurt, respectively [8].

4. Food Additives—Their Role in Modern Diets

Over time, human interactions with and preferences for food have changed from the need for survival to more nutritional aspects, such as quality, health effects and food safety. The increased consumer interest in these issues drives the food industry, together with the research community, to develop new methodologies and new foods [21,61].

Eating habits are influenced by several factors, such as demographic, socio-economic, cultural, political and environmental factors, which impact food processing, monitoring and conservation. Easy conservation, low environmental impact and the search for healthier foods are some of the biggest demands of the consumer. For healthy eating, there is a desire not only for foods that are not harmful but also to prevent diseases such as diabetes and heart problems [62].

According to the Codex Alimentarius, a food additive is defined as “any substance not normally consumed as food by itself and not normally used as a typical ingredient of the food, whether it has nutritive value, the intentional addition of which to food for a technological (including organoleptic) purpose in the manufacture, processing, preparation, treatment, packing, packaging, transport or holding of such food results, or may be reasonably expected to result (directly or indirectly), in it or its by-products becoming a component of or otherwise affecting the characteristics of such foods” [63].

Food additives are used for their diverse functions, including reducing food perishability and microbial degradation, giving color or flavor to foods, and their acidity, among others, ensuring their safety and improved characteristics, besides avoiding waste, and ensuring greater food variability for the population [64].

There are certain variables that influence the consumer’s perception of additives, which include cultural milestones about additives, published studies on related risks and public opinion in the media and social networks. The public uses what they know and their own experiences to relate to new market trends, since they have little accessibility to information. Additives, especially, are strongly influenced if there is a negative consumer perspective, which can totally change their acceptability [65].

The “E numbers”, codifications made for additives, when implemented in the 60s, were seen in the beginning from the consumer perspective as an advantage if it was present on the label, since it ensured that the food was safe for consumption. Currently, the situation is the opposite since the encoding represents something unknown [66].

Among the trends for the food industry, there is the use of the “clean label”, for which there is no concrete definition, but it can be described as a label that contains a short list of ingredients, excluding names that look like chemicals of the “E numbers” [67]. Although the public prefers foods that do not contain additives, if this is not possible, the consumer will choose foods containing natural additives rather than synthetic ones [68].

Another factor that is related to the insecurity of the consumption of synthetic additives is the research identifying these as hazardous compounds to health, associating them with their carcinogenic and mutagenic potential and allergenic properties. In addition, they are also seen as guilty due to the increased use of chemicals in the world and as responsible for altering the natural composition of foods [65].

Among the prohibited synthetic additives, there is the azodicarbonamide, banned in Australia and Europe, used as a bleaching agent in flours and presenting allergic properties.

Besides that, when heated, it generates traces of semicabazide (SEM), on which studies were carried out pointing it out as genotoxic and in certain cases, as causing tumors [69]. Potassium bromate is also used in the bakery industry, generating greater elasticity for the dough and contributing to the growth of bread. However, this food additive was banned because studies initially showed nephrotoxic activity, besides being later able to generate neuropathological disorders and carcinoma in a renal cell of rats [70]. Butylated hydroxy anisole (BHA) and butylated hydroxytoluene (BHT) have been used for many years for their antioxidant and preservative capacity, besides maintaining the freshness of the food; however, it has been banned in several countries for its toxicity, presenting carcinogenicity in animals [71].

For the synthetic additives that are still commercialized, phosphates are widely used in the meat industry due to their preservative capacity, but studies have shown its relationship to kidney diseases and cardiovascular problems such as coronary calcification [72]. Potassium sorbate is used for its preservative property, inhibiting molds in dairy products. Although potassium sorbate is metabolized and oxidized to carbon dioxide and water, if consumed in amounts greater than 25 mg/kg, problems with its cytotoxicity and genotoxicity can occur, producing mutagenic compounds [73]. Sulfites are used to inhibit enzymatic and non-enzymatic browning reactions, besides being an antimicrobial and antioxidant agent, and this additive has a cytotoxic and carcinogenic effect in rats and humans [74]. The above-mentioned additives, as well as others, are seen by consumers as harmful, even though most of the toxicological data have proven their safety in recent years throughout several evaluations. Still, the consumers prefer natural additives or no additives at all on their plates, and thus, the use of by-products that enhance flavor, taste and appearance and may have a technological effect can help reduce the need for the “chemicals”.

5. Trends towards Natural Additives

Although there is no definition of the term in legislation, the Food and Drug Administration (FDA) considers “natural” as a food that “does not contain anything artificial or synthetic, including additives” [75]. During the past few years, there has been greater research and demand for natural foods due to studies showing adverse effects on the use of synthetic additives. Besides that, the use of the term “natural” increases the value of the product due to the new trend in relation to the consumption of products containing only natural ingredients [76,77].

Plants, fruits and spices are recognized due to the presence of compounds beneficial to health. Among food additives, the biologically active substances presented in plants can be classified as antioxidants, antimicrobials, flavorings, colorants and others, as a non-official classification. With greater public awareness of consuming natural products, more research has been performed, generating promising sources of natural additives [78].

By-products and biowaste from the food industry represent tons of raw materials that are rich in bioactive molecules. For instance, orange peels contain essential oils, pectin, cellulose, hemicellulose and soluble sugars (glucose, fructose, sucrose and galactose), making it possible to use them as additives such as flavorings, sweeteners and antioxidants [79]. With greater consumer demand for additives from natural sources and a mindset based on sustainability, the use of vegetable by-products and bio-residues is an alternative to synthetic additives [80]. Figure 4 shows some of the possible co-products that can be used as additives, and Table 2 exemplifies some compounds that are natural additives, as well as the food from which they can be extracted.

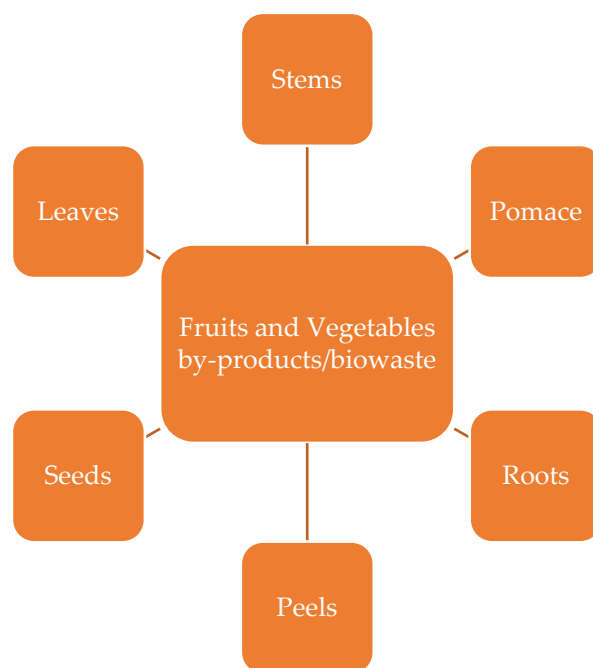


Figure 4. Co-products and bio-residues that can be used as a source of food additives.

Table 2. Natural FV by-product sources and bioactive compounds considered as additives.

Additive	Compound	GRAS Status/EU E Number	By-Product or Residue	Food Application	References
Antioxidants	β -carotene	GRAS/E160a	Carrot peel	Meal replacement bar	[81,82]
	Ascorbic acid	GRAS/E300	Apple pomace	Bread	[83,84]
	Tocopherol	GRAS/E306	Apple seeds	Dry-cured bacon	[85,86]
Antimicrobials	Essential oils	Not GRAS/No E number	Grapefruit peel	Ham	[87,88]
	Flavonoids	GRAS/No E number	Bergamot peel	Fresh pork meat	[89,90]
	Catechins	Not GRAS/No E number	Avocado peel and seed	Pork patties	[91]
	Limonene	Not GRAS/No E number	<i>Citrus deliciosa</i> peel	Edible films	[92,93]
Colorants	Lycopene	GRAS/E160d	Tomato peel	Dye beverages	[94,95]
	Anthocyanins	Not GRAS/E163	Blueberry pomace	Confectionery products	[96,97]
	Chlorophyll	Not GRAS/E140	Spinach by-products	Ice cream	[98,99]
Sweetener	Xylitol	GRAS/E967	Banana peel Almond shell	Rusks Cashew juice	[100–102]
Emulsifier/stabilizer	Cellulose	GRAS/E460	Banana bract (BB) and peel (BP)	Sausage	[103,104]
	Pectin	GRAS/E440	Passion fruit peel	Ice cream	[105,106]
Antibrowning	Thiols	Not GRAS/No E number	Onion bagasse	Fresh-cut avocado	[107]

5.1. Antioxidants

Oxidation can decrease the quality of food either by change in its organoleptic properties, the destruction of nutrients or the production of toxic compounds. Antioxidants

are used to solve this problem, widely used in food products to reduce the effect of free radicals and consequently lipid oxidation, for example [108].

Natural antioxidant compounds are capable not only of delaying the oxidation process of food and consequently increasing their shelf life, but also attributing beneficial properties to the consumer's health, such as a protective effect on gastrointestinal tracts, efficient in inflammatory and cardiac events, but also in the help of neural and hepatic complications [109,110].

Phenolic antioxidants are a group of compounds that have been studied due to their antioxidant capacity and are present in several food products, mainly in fruits and vegetables. Regarding antioxidant capacity, tocopherols, ascorbic acid and rosemary extract components (e.g., carnosol and carnosic acid) are the most studied compounds [111].

Hernández-Carranza et al. (2016) highlight a relevant amount of vitamin C, flavonoids and phenolic compounds present in apple pomace and orange and banana peels. The largest amounts of phenolic compounds and vitamin C were found in orange (729 mg of GAE/100 g dw and 96 mg of ascorbic acid/100 g dw, respectively), while the largest content of flavonoids (752 mg of catechin/100 g dw) was present in the banana peel [83].

The application of ascorbic acid to whole-grain breads can cause a 40% reduction in primary lipid oxidation during the 2 days of shelf life, being a viable option to prolong bread stability [84].

Chantaro et al. (2008) evaluated the antioxidant capacity of dietary fiber powder by drying carrot peels, finding a content of β -carotene of 20.45 mg/100 g dw and a content of total phenolic compounds of 1371 mg GAE/100 g dw. Despite the carrot skins having β -carotene content below the inner part, it showed high antioxidant activity (94.67%) [81]. The application of β -carotene in meal replacement bars can reach a concentration of 9.72 mg/100 g after the cooking process, achieving the amount of β -carotene needed for people [82].

Górnás (2015) characterized the profile of tocopherols (T) present in apple seeds, finding a relevant concentration of the α -T (114.55), β -T (124.28), γ -T (78.69) and δ -T (79.03 mg/100 g oil), showing itself as a promising natural source of vitamin E [85].

Furthermore, the incorporation of polyphenols and α -tocopherol from plant extracts to bacon can significantly reduce lipid oxidation from the formation of reactive substances of Thio barbituric acid, protecting the bacon from oxidation during dry-curing processing (0.04 to 0.44 MDA/kg between the raw product up to 3 weeks of storage, respectively) [86].

5.2. Sweeteners

New sugar alternatives such as allulose have a similar sweetness profile to sucrose. The downside of allulose is its scarcity in nature, and thus using by-products to obtain it could be an alternative to obtain it in higher quantities and lower prices [112]. Recent studies have shown that almond skin can be used as a source of xylo-oligosaccharides, a substance used to produce xylitol, a low-caloric sweetener used in foodstuff. Moreover, it also reports several compounds present in the skin, such as some hydroxybenzoic and hydroxycinnamic acids, anthocyanidin and procyanidin, compounds studied for their ability to prevent degenerative and cardiovascular diseases [101]. The cashew juice can also be used as a source of sweetener, presenting a sensory profile like that of artificial sweeteners [102].

Rehman et al. (2013) carried out the biotechnological production of xylitol from the banana peel, using *Candida tropicalis* DSM 7524 for the transformation of xylose into xylitol, applying it later to toast and checking for possible physico-chemical changes in the food. The use of banana peels proved to be a good source of xylitol production, obtaining L-arabinose (57.35), D-xylose (67.80), D-galactose (42.04) and glucose (4.71 g/L). For the application, xylitol showed no differences in physical and chemical characteristics over the shelf life, remaining stable for 30 days [100].

5.3. Antimicrobials

Microbial contamination is one of the biggest concerns regarding food safety due to associated pathologies, with new alternatives being always found to overcome this problem, especially without changing the food characteristics [113]. Antimicrobials are defined as compounds whose aim is to extend the shelf life of foods by inhibiting the growth of microbial cells or killing them, which can be of animal origin, through microorganisms or plant sources. Among the plant origin antimicrobials, they can be classified into saponins, flavonoids, terpenes, polyphenols, and several others, in which these compounds can be obtained through plant extracts, such as essential oils [114,115].

The extension of shelf life by antimicrobials can occur through direct Incorporation of additives in foods or application of these additives in packaging materials, indirectly resulting in the extension of the shelf life. Due to the wide variety of antimicrobial compounds from fruits and vegetables, they maybe have different mechanisms of action (e.g., action in the cell membrane's rupture, affect nucleic acid mechanisms and depletion of adenosine triphosphate) [116].

Rodríguez-Carpena et al. (2011) evaluated the antimicrobial capacity of avocado residues, such as peels and seeds, applied to pork burgers. In one of the avocado varieties, called "Fuerte", a significant amount of catechins (751.9 mg/100 g dw) and procyanidins (13484.3 mg/100 g dw) were found in the phenolic profile of the peel. Finally, avocado residues showed a moderate antimicrobial effect against Gram-positive bacteria [91].

Mandalari et al. (2007) investigated the antimicrobial activity of flavonoids from the bark of bergamot, with a minimum inhibitory concentration between 200 and 800 µg/mL for pure flavonoids (neo hesperidin, hesperetin, neoeriocitrin, eriodictyol and naringenin). The flavonoids were efficient against all the Gram-negative bacteria evaluated (*Escherichia coli*, *Pseudomonas putida* and *Salmonella enterica*) [71]. Flavonoids can also have a retarding effect on microbial growth in fresh pork, besides decreased color loss and oxidation of myoglobin when stored under refrigeration [90].

Okunowo et al. (2013) studied the essential oils obtained from the pomelo peel in terms of its antimicrobial activity, identifying 95.26% of the entire profile of essential oils in the peel, with the compounds D-limonene having the highest concentration (75.07%). The essential oil, when used as an oil-methanol mixture, could inhibit all bacteria and fungi studies, suggesting a source of natural antimicrobial [87]. The incorporation of those essential oils into ham can generate a reduction in microbial growth of up to 19% against *Listeria monocytogenes*, but can also attribute strong flavoring properties, limiting their use for food application [88].

5.4. Colorants

The food color is fundamental to determine its acceptance, as it affects the consumer's perception of quality [117]. From this, the use of pigments and colorants becomes a way of attracting the consumer, in which natural colorants (carotenoids, anthocyanins, betanin and chlorophylls) also bring beneficial effects to health besides their color effect [118].

Crizel et al. (2016) evaluated the blueberry bagasse to obtain anthocyanins, a substance capable of exercising a colorant function. The by-product powder showed a good amount of anthocyanins (2063.4 mg/100 g), with the compound delphinidin 3-glucoside being the anthocyanin with the highest amount (824.9/100 g) [96]. The blueberry bagasse also proved to be an effective natural colorant, besides increasing the antioxidant and antimicrobial capacity of confectionery products incorporated with anthocyanins, showing a promising colorant for food application [97].

Knoblich et al. (2005) used tomato peels as a source of carotenoids, obtaining a lycopene concentration of 734 µg/g, which can be used as a coloring agent [94]. Oliveira et al. (2017) applied lycopene in beverages (yogurt and apple-flavored soy drink), obtaining a relevant hygroscopic characteristic and with colors like those produced in the market [95].

Derrien et al. (2017) extracted chlorophyll from spinach industry waste with a maceration process and 95% ethanol, finding a concentration of 112.75 mg/100 g fw [98]. Durmaz

et al. (2020) used chlorophyll as a natural colorant in ice creams from a spray drying process, generating a significant difference in color and promoting an attractive color for the food [99].

5.5. Other Additives

Harini et al. (2018) extracted cellulose fibers from banana bracts and peels using the microwave digestion method, presenting high amounts of the compounds (55.48% and 64.67% for the peels and the bracts, respectively) [103]. Zhao et al. (2018) evaluated the physico-chemical and sensory properties of sausages with low fat content and the addition of cellulose fiber, improving the stability of their emulsion, hardness, viscosity and chewability and being effective in reducing the fat content, without affecting the other properties [104].

Roldán et al. (2008) characterized the by-products from onion (juice, paste and bagasse), in addition to assessing the antioxidant capacity and inhibition of polyphenol oxidase (PFO) in freshly cut avocados. The bagasse was able to present a relevant antioxidant activity, a moderate composition of bioactive compounds and a significant effect against enzymatic browning (relative enzymatic activity of 86.08%), being a natural anti-browning alternative for the food industry [107].

Seixas et al. (2014) extracted the pectin from the passion fruit peel, a substance used as a gelling, stabilizing and emulsifying agent, obtaining a yield of up to 18.2% [105]. The pectin extracted from by-products can produce stable emulsions, besides being used in much lower concentrations, when compared to gum Arabic, for example. Lastly, the use of pectin in ice cream can increase the viscosity in addition to slowing the melting point of the product [106,119].

6. Trends and Conclusions

The waste generated in the food industry and the environmental problems caused are both concerns that reflect themselves in all countries, whether developed or still developing. Fruits and vegetables, as well as their by-products and bio-residues, are foods that have several beneficial health properties and are widely studied around the world.

Using synthetic additives and their health-related problems brings a negative consumer perspective, assimilating these compounds with potential carcinogenic and allergenic effects. Therefore, this factor added to the need to reuse those by-products and bio-residues generated from plants demonstrate the importance of studying the application of by-products and bio-residues as a source of natural additives.

Obtaining the compounds of interest from these alternative raw materials in an efficient and safe way is still a challenge for the industry, and the increase in interest drives the development of new technologies. Hence, the application of extraction methods in concomitance with current demands for sustainability is an important factor for the acquisition of compounds with quality and health benefits, for instance, the use of non-conventional extraction methods and optimization studies. Microwave-assisted, ultrasound-assisted, enzyme-assisted, pulsed electric field and supercritical fluid extractions are examples of non-conventional methods that present themselves as potential alternatives for the extraction of bioactive components in diverse food matrices in a faster, greener and more efficient way with less solvent consumption.

Despite the potential for using those raw materials as a source of natural additives, the regulatory aspect must be considered. For them to be employed in food products, they must be within the safety parameters for consumers and must be accepted by food regulatory agencies for further implementation. The management of residues and the economic aspect are other challenges for the industry, because applications in large scales still present high costs, despite the technological advances.

Therefore, despite all the challenges, the use of bio-residues from FV as a source of high-value molecules is a promising alternative, considering the current demands for sustainability and for achieving the circular economy.

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