

Fresh Fruit and Vegetable Waste in Human Health

Subjects: Agriculture, Dairy & Animal Science | Others

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Food supply disruption and shortage verified during the current pandemic events are a scenario that many anticipate for the near future. The impact of climate changes on food production, the continuous decrease in arable land, and the exponential growth of the human population are important drivers for this problem.

Keywords: bioactive compounds ; fruit waste ; vegetable waste ; health ; disease ; peels ; seeds

1. Introduction

According to UN estimates, the world's population will reach 9.8 billion by 2050, nearly 20% higher than today ^[1]. This exponential increase combined with continuous climate changes, water scarcity, and decreasing of agricultural areas constitutes societal and global problems that challenge food production for the next generations. With current global trends in diets, the exponentially growing population and considering the several millions of tons of food that are lost and wasted every year in different steps of the food chain, including production, post-harvesting, processing, and distribution, in 2050 50–60% more food will be needed than today to feed everyone. These overwhelming numbers clearly show that food challenges and planet sustainability are intrinsically bound and must determine urgent measures to mitigate them. It will be important to develop strategies to produce more food and better food with less waste. In addition, the implementation of sustainable food production systems through the optimization of food processes will be essential to achieve a better environmental footprint, lower production costs, and improve the quality and nutritional value of food (Figure 1).

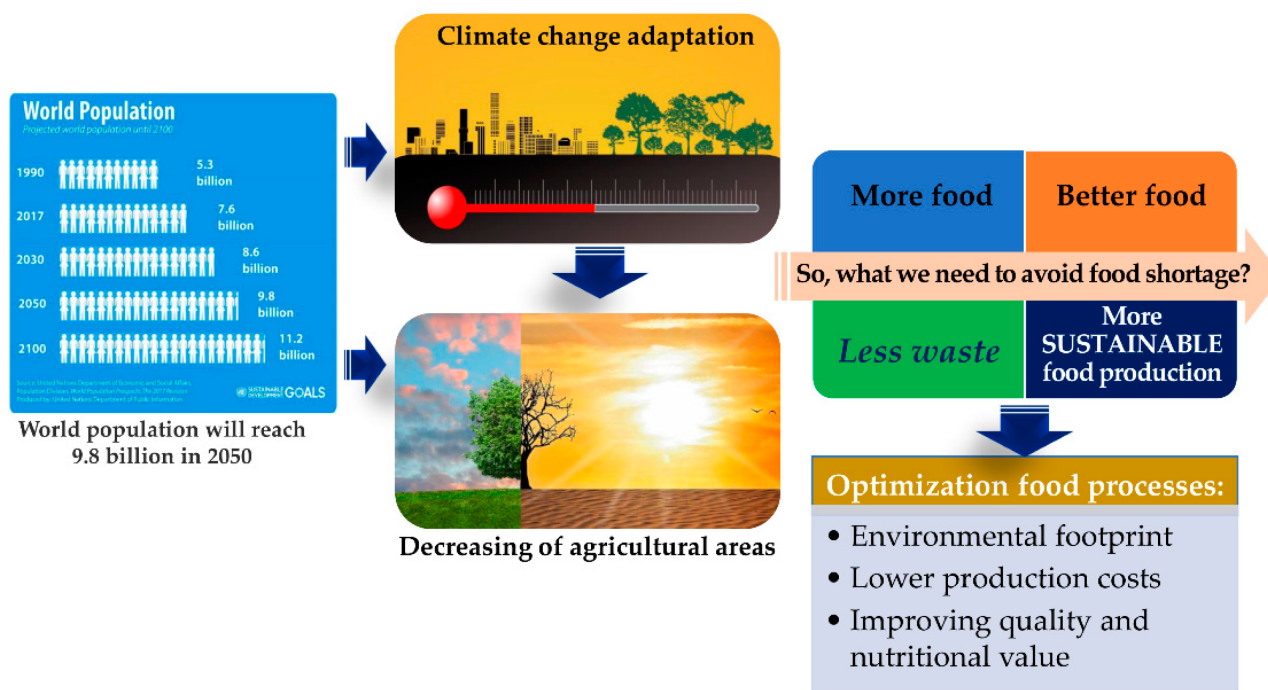


Figure 1. Global and societal challenges in the production of foods for the next generations.

Given these facts, the European Commission established food waste as one of the priority areas of the Action Plan for the European Circular Economy Strategy ^[2]. This includes a zero-waste strategy envisaging agri-food waste to reduce environmental pollution. This strategy is based on the extraction of compounds from food waste that have a high demand or innovative applications with potentially high economic return in different industrial sectors, such as nutraceutical, cosmetic, and pharmaceutical industries ^{[3][4]}. In this context, the extraction of phytochemicals from fruit and vegetable waste able to substitute the use of synthetic preservatives in food products and confer additional health protection effects

to the researchers diet is of utmost importance [3][4][5][6]. However, these strategies mostly target the food industries and food chain stakeholders and not the final consumer. Remarkably, almost half of the losses and waste in fruits and vegetables are caused by human eating habits, being the second cause of greenhouse gas emission. Statistically, this is equivalent to 1.3 billion tons of wasted foods causing the emission of around 4.4 gigatons of greenhouse gas [1]. This means that every one of us, as final consumers, has important responsibilities to share when a great part of food waste occurs on the supermarket shelves and in the researchers kitchens and fridges. This includes the fruits and vegetables that are rejected because of their non-standardized measures or defects, commonly known as ugly foods, but also the peels, seeds, rinds, or cores, which despite being edible and rich in nutrients and bioactive compounds, are discarded to the food waste bin.

2. Nutritional and Bioactive Potential of Fresh Fruit and Vegetable Waste

According to the most recent data available, approximately half of fruits and vegetables produced worldwide are wasted. This represents around 1.3 billion tons of wasted foods and constitutes the second highest cause of greenhouse gas emission, representing the emission of around 4.4 gigatons of greenhouse gas [7]. However, beyond the obvious environmental impact, this means that millions of tons of nutrients present in this food waste are being lost. Additionally, this is happening on the same planet where currently more than 500 million people do not have access to enough food to live, and the problem will be exacerbated as the world population continues to grow exponentially [7]. It is, therefore, imperative that each consumer contributes to wasting less food and part of that objective can be easily achieved just by integrating into the researchers diet fruits and vegetables that the researchers wrongly considered as inedible. The list of fruits and vegetables used in the human diet is potentially endless and so here is focused on those with higher production and impact in terms of waste being discarded that can and should be further used in the researchers diet. Their nutritional and bioactive potential is reviewed below in detail and summarized in **Table 1**. It should be noted, however, that this behavioral change should be accompanied by due diligence regarding food safety. Fruit and vegetable peels are often loaded with microorganisms and agrochemicals that should be thoroughly removed to maintain safety.

Table 1. Main fruits and vegetables consumed worldwide with a rich bioactive waste composition.

Fruit or Vegetable	Edible Part Composition: Nutritional and Bioactive Value	Discarded Part Composition: Nutritional and Bioactive Value	Possible Dietary Uses	Preparation	Ref.
Fruit					
Apple	flesh: flavan-3-ols, phenolic acids, flavonols, dihydrochalcones, anthocyanins, and ascorbic acid	peel: phenolic compounds (chlorogenic acid, procyanidin B2, epicatechin)	edible	wash to eliminate	[8][9][10]
			vinegar	pesticides and other	
Banana	flesh: fiber, carbohydrates, phenolics, biogenic amines, phytosterols, minerals; low-fat content	peels: crude fiber, carbohydrates, crude protein, phenolics, minerals	cider	contaminants	[11][12][13][14]
			edible after cooking	softened before ingestion (cooked)	
			banana peel flour	washed to eliminate	
			fermented beverages	pesticides and other contaminants	

Fruit or Vegetable	Edible Part Composition: Nutritional and Bioactive Value	Discarded Part Composition: Nutritional and Bioactive Value	Possible Dietary Uses	Preparation	Ref.
Citrus	flesh: carbohydrates, amino acids, polyphenols, flavonoids, vitamin C, minerals	blossoms: saponins, flavonoids, glycosides, tannins, steroids, phenols, minerals, vitamins	edible after cooking	softened before ingestion (cooked)	[15]
				washed to eliminate pesticides and other contaminants	
Grape	flesh: carbohydrates, organic acids, terpenoids, vitamins, minerals, polyphenols	peel: fiber, polyphenols, flavonoids, carotenoids, vitamin C, limonoids, essential oils	citrus peel powder to flavor tea	washed to eliminate pesticides and other contaminants	[14] [16] [17] [18]
Grape	flesh: carbohydrates, organic acids, terpenoids, vitamins, minerals, polyphenols	skin: phenolic acids, stilbenes, flavanols, flavonols, anthocyanins, polysaccharides, dietary fiber	natural food additive	softened before ingestion (cooked)	[19] [20] [21] [22] [23] [24] [25] [26]
Kiwi fruit	flesh: dietary fiber, phenolic compounds, vitamins, minerals	seeds: unsaturated fatty acids, vitamin E, sterols, minerals	grape pomace flour	washed to eliminate pesticides and other contaminants	[27] [28] [29]
Mango	flesh: rich in dietary fiber, carbohydrates, proteins, fats, and phenolic compounds	peel: rich in dietary fiber, phenolic compounds, carotenoids, vitamins C and E, minerals	edible	washed to eliminate pesticides and other contaminants	[30] [31] [32] [33] [34]
Mango	flesh: rich in dietary fiber, carbohydrates, proteins, fats, and phenolic compounds	peel: rich in dietary fiber, phenolic compounds, carotenoids, vitamins C and E, minerals	mango peel flour	washed to eliminate pesticides and other contaminants	[14] [30] [31] [32] [33] [34]
Mango	flesh: rich in dietary fiber, carbohydrates, proteins, fats, and phenolic compounds	seeds: rich in flavonoids, phenolic acids, and fats	mango seed	softened before ingestion (cooked)	[15]
				washed to eliminate pesticides and other contaminants	
Mango	flesh: rich in dietary fiber, carbohydrates, proteins, fats, and phenolic compounds	peel: fiber, polyphenols, flavonoids, carotenoids, vitamin C, limonoids, essential oils	citrus peel powder to flavor tea	washed to eliminate pesticides and other contaminants	[14] [16] [17] [18]
Mango	flesh: rich in dietary fiber, carbohydrates, proteins, fats, and phenolic compounds	seeds: unsaturated fatty acids, vitamin E, sterols, minerals	grape pomace flour	washed to eliminate pesticides and other contaminants	[19] [20] [21] [22] [23] [24] [25] [26]
Kiwi fruit	flesh: dietary fiber, phenolic compounds, vitamins, minerals	peel: rich in carbohydrates, dietary fiber, lipids, protein, phenolic compounds, vitamins C and E	edible	washed to eliminate pesticides and other contaminants	[27] [28] [29]
Mango	flesh: rich in dietary fiber, carbohydrates, proteins, fats, and phenolic compounds	peel: rich in dietary fiber, phenolic compounds, carotenoids, vitamins C and E, minerals	mango peel flour	washed to eliminate pesticides and other contaminants	[14] [30] [31] [32] [33] [34]
Mango	flesh: rich in dietary fiber, carbohydrates, proteins, fats, and phenolic compounds	seeds: rich in flavonoids, phenolic acids, and fats	mango seed	softened before ingestion (cooked)	[15]
				washed to eliminate pesticides and other contaminants	

Fruit or Vegetable	Edible Part Composition: Nutritional and Bioactive Value	Discarded Part Composition: Nutritional and Bioactive Value	Possible Dietary Uses	Preparation	Ref.
Passion fruit	flesh: vitamin A and C, minerals, dietary fiber, protein, phenolic compounds	peel: fiber, pectin, phenolic compounds, and minerals	passion fruit	washed to	[35]
			peel flour	eliminate	[36]
			natural food additive	pesticides and other contaminants	[37] [38] [39] [40] [41] [42] [43]
Pear	flesh: sugars, vitamins, organic and fatty acids, amino acids, volatiles, polyphenols, minerals	seeds: fats	edible		
		peel: arbutin, chlorogenic acid, catechin, quercetin, kaempferol, hydroxycinnamoylmalic acids and their ethyl esters, procyanidins and triterpenes	edible	washed to eliminate pesticides and other contaminants	[44] [45]
Peach	flesh: dietary fiber, minerals, sugars, organic acids, phenolic compounds, carotenoids, volatiles	peel: polyphenols (flavanols, hydroxybenzoic, hydroxycinnamic acids, flavonols), carotenoids	edible	washed to eliminate pesticides and other contaminants	[46] [47] [48]
Pineapple	flesh: carbohydrates, dietary fiber, sugars, organic acids, vitamins, minerals	peel and rind: carbohydrates, proteins, pectin, bromelain, phenolic compounds	vinegar production		
			tepache (a fermented beverage)	washed to eliminate pesticides and other contaminants	[49] [50] [51]
			flour production		[52]
			natural food additive		
Plum	flesh: phenolic compounds (chlorogenic and gallic acids, resorcinol, and rutin) and ascorbic acid.	core: fiber, bromelain, vitamin C	edible	softened before ingestion	
		peel: polyphenols (flavonoids, anthocyanins), ascorbic acid.	edible	washed to eliminate pesticides and other contaminants	[53] [54] [55]
		seeds: dietary fiber, protein, fat, cucurbitin, minerals, tocopherol.	edible	external layer must be softened before ingestion (cooking)	[56] [57] [58] [59] [60] [61] [62] [63]
			natural food additive		

Fruit or Vegetable	Edible Part Composition: Nutritional and Bioactive Value	Discarded Part Composition: Nutritional and Bioactive Value	Possible Dietary Uses	Preparation	Ref.
Watermelon	flesh: glycosides, carotenoids, flavonoids, alkaloids, carbohydrates, fatty acids, essential oils.	rind: phenolic compounds, citrulline, pectin.	natural food additive		[64] [65] [66] [67] [68]
		seeds: dietary oil, minerals, vitamins, phenolic compounds	watermelon seed oil		
Vegetables					
Broccoli	florets: minerals, vitamins, phenolic, flavonoid compounds	stalks: phenolic compounds, sugars, pectic polysaccharides, free amino acids, glucosinolates, pectin	edible after cooking	softened before ingestion (cooked)	
			natural food additives (soups, flours, tea, pasta)	washed to eliminate pesticides and other contaminants	[69] [70] [71]
Cauliflower	florets: fiber, minerals, phenolics, ascorbic acid, carotenoids, glucosinolates	stems and leaves: carbohydrates, protein, fat, glucosinolates dietary fiber, minerals	edible after cooking	softened before ingestion (cooked)	
			leaf powder (food supplement)	washed to eliminate pesticides and other contaminants	[72] [73] [74]
Potato	flesh: carbohydrates, polyphenols, vitamins, and minerals	peel: glycoalkaloids, polyphenols. non-starch polysaccharides, proteins, lipids, lignin, cellulose	edible after cooking	softened before ingestion (cooking)	[75] [76]
			natural food additive	washed to eliminate pesticides and other contaminants	[77] [78] [79]
Pumpkin	flesh: dietary fiber, carotenoids, phenolic acids, flavonols, minerals, vitamins	peel and rind: dietary fiber (pectins), carotenoids, phenolic acids, flavonols, minerals, vitamins	edible after cooking	softened before ingestion (cooking)	
			natural food additive	washed to eliminate pesticides and other contaminants	[80] [81]

2.1. Fresh Fruits

2.1.1. Apple

Apples are one of the most consumed fruits in Europe, and they are a great source of several bioactive compounds, especially phenolic compounds such as flavan-3-ols, phenolic acids, flavonols, dihydrochalcones, and anthocyanins. Furthermore, apples present a high content of ascorbic acid [8]. Apple waste is mainly composed of peels that are rich in bioactive compounds, in concentrations even higher than in the flesh. Apple peels are an important source of polyphenols, being the most abundant chlorogenic acid, procyanidin B2, and epicatechin [9].

2.1.2. Banana

The edible banana fruit (*Musa spp.*) is soft and sweet, and usually eaten raw. In contrast, plantain bananas (*Musa × paradisiaca*) have a firm and starchy pulp suitable for cooking as a vegetable. Both are seedless fruits, rich in carbohydrates, dietary fibers, certain vitamins, minerals (such as phosphorus, sodium, potassium, calcium, magnesium, iron, copper, zinc, and manganese), and several health-promoting bioactive phytochemicals [11]. Different studies have identified many of these bioactive compounds, such as carotenoids (β -carotene), flavonoids, phenolics, biogenic amines, vitamins A, B, C, and E, and phytosterols [11][12][82][83]. Extracts from different parts of banana fruit and plants were shown to elicit effective protection against oxidative damage to cells and different human diseases triggered by these deleterious events, notably different forms of cancer (reviewed in [84]). These effects are possibly associated with the existence of specific phytoconstituents in banana plants and fruit, including ferulic acid, protocatechualdehyde, 2-pentanone, 4-epicyclomusalenone, cycloeucalenol acetate, and chlorogenic acid, which have been shown to exhibit therapeutic cancer-preventing and anticancer abilities (reviewed in [84]). These bioactive compounds have been widely shown to have many positive effects on human health and banana has an effective antioxidant capacity higher than many berries [85]. This phytochemical composition certainly explains the efficiency of the traditional uses of bananas against degenerative diseases triggered by oxidative stresses [12]. Among the flavonoids found in bananas are quercetin, myricetin, kaempferol, and cyanidin [11][86]. Banana has been shown to contain a good amount of phytosterols, such as stigmasterol, β -sitosterol, campesterol, 24-methylene cycloartenol, cycloeucalenol, and cycloartenol, as well as a group of biogenic amines, the catecholamines [11]. In particular, the composition of the biogenic amines L-dopa and dopamine in banana makes this fruit very relevant as a supplement in the treatment of Parkinson's disease [82].

In contrast, and with exception of some producing countries in Asia and Latin America, banana peel and other parts of the fruit and plant are traditionally discarded in soil and used as compost to provide nutrients for the next harvests. However, banana peel is also rich in anthocyanins (delphinidin) and cyanidins [11], as well as in β -carotene, gallic acid, and vitamins A, C, and E [87][88]. Additionally, it has a high content of dietary fibers, including hemicellulose and pectin polysaccharides [87]. Like the pulp, banana peels are also rich in phytosterols and catecholamines (biogenic amines). Borges, et al. [89] reported that banana peel showed superior phenolic compound and mineral levels compared to pulp. This composition of banana peels certainly explains the bioactive effects reported in traditional uses to promote wound healing, mainly from burns, and to help overcome or prevent several illnesses, such as depression [82].

The banana rhizome is very rich in phenolic compounds with important antioxidant activities [90]. The main phenolics found include ferulic, sinapic, salicylic, gallic, p-hydroxybenzoic, vanillic, syringic, gentisic, and p-coumaric acids, besides catechin, epicatechin, tannins, and anthocyanins [11]. Banana flowers or blossoms are also treated as agricultural waste when they are extirpated from the plant during the growing process, as they compete for the nutrients necessary for the growing fruit [91]. However, high amounts of different bioactive compounds, such as umbelliferone and lupeol, have been reported in ethanol extracts of banana flowers [92]. Part of these bioactive compounds has potential against cardiovascular diseases and diabetes. Evidence of such effects was provided by Wistar rats fed with an experimental diet incorporating banana blossom, which revealed modulation of hypocholesterolemic and hypoglycemic responses [84]. Recently, Sheng, et al. [93] also provided evidence that banana flower phytosterols, notably β -sitosterol, have the potential to prevent diseases associated with abnormal blood sugar and AGE levels, such as diabetes. Finally, extracts from the bracts of the banana flower were shown to contain anthocyanins (delphinidin, pelargonidin, peonidin, and malvidin), alkaloids, glucosides, flavonoid and phenolic compounds, saponins, terpenoids, coumarins, and steroids [91], as well as minerals (K, Cu, Ca, Fe, and P) and vitamins (A, C, and E) [15].

2.1.3. Citrus Fruit

Citrus fruits, mainly orange and lemon, are very popular worldwide. These fruits are rich in carotenoids, flavonoids, terpenes, limonoids, and many other bioactive compounds of nutritional and nutraceutical value, including polymethoxylated flavones (PMFs). These flavones were shown to elicit several bioactive effects against metabolic disorders, atherosclerosis, inflammation, neuroinflammation, cancer, and oxidation (reviewed in [94]). In addition, citrus essential oils are rich in limonoids and terpenes, which are widely appreciated for their antioxidant, antimicrobial, and

flavoring properties with broad industrial applications [94]. Citrus peels are the main residue originating from citrus fruit, being very rich in dietary fibers (cellulose, hemicellulose, and pectin), bioactive compounds (phenolic compounds, flavonoids, and carotenoids), and vitamin C [18][95][96]. A myriad of bioactive compounds has been reported in citrus peels. A study recently conducted by Yaqoob, et al. [97], for instance, revealed that kinnow peel contains six flavones, eight flavon-3-ols, five flavanones, four flavan-3-ols, one anthocyanin, phenolic acids, and limonoids. Other reports point to citrus peels as promising sources of naringin, β -carotene, hesperidin, neohesperidin, and pectin [98][99]. Tangerines grown in Madeira, for instance, have a very intense and unique aroma which is mainly due to the presence of high amounts of volatile bioactive compounds in their peels, including thymol and dimethyl anthranilate [100]. Overall, citrus peels gained considerable attention due to their content in essential oils, mainly constituted by a mixture of volatile compounds such as terpenes (limonene) and oxygenated derivatives such as aldehydes (citral), alcohols, and esters [17][99].

2.1.4. Grape

Grape is a fruit crop with a wide range of products, from fresh fruit and juice to other highly processed products, such as jelly and wine. Interest in these products is greatly related to the high content of phytonutrients belonging to numerous families, such as carbohydrates, organic acids, terpenoids, vitamins, and minerals, but most importantly polyphenols [22]. Studies have proved that these health-promoting compounds are highly accumulated in the skin, seeds, stems, and leaves of grapes [22][101]. Several studies have identified various phenolic compounds in grape skins, including phenolic acids, stilbenes, flavanols, flavonols, and anthocyanins [19][23][26], namely malvidin-3,5-di-O-glucoside and the flavanol quercetin- β -D-glucoside [102]. Regarding the nutritional value of grape pomace, it can be observed that red grape varieties are rich in dietary fibers, consisting mainly of lignin, cellulose, and hemicellulose [21]. Grape seeds' most relevant component is oil, which is rich in unsaturated fatty acids, such as linoleic and oleic acids, vitamin E, and sterols. Seeds also present significant amounts of essential minerals, predominantly K, Fe, and Zn [24].

2.1.5. Kiwi Fruit

Kiwi fruit is one of the most commercialized fruits in the international markets and is loaded with nutrients such as vitamins, minerals, and a myriad of bioactive compounds [28][29]. Its peel is a source of macronutrients, namely carbohydrates, dietary fiber, lipids, proteins, and vitamins C and E [27]. It also presents high biological activity due to the content in phenolic compounds, such as flavonoids, organic acids (quinic, malic, and malic), epicatechin, and anthocyanins [29]. Kiwi fruit skin has been reported to exert higher antioxidant, antibacterial, and anticancer activities than the pulp [103].

2.1.6. Mango

Mangoes are one of the most popular fruits worldwide, and their production causes high amounts of waste. Mango peels and seeds are the main byproducts produced, having a considerable concentration of bioactive compounds [32]. Mango peel is rich in vitamins C and E, and in several minerals (Ca, K, Mg, Na, Fe, Mn, Zn, and Cu) [33], and contains pectins and anthocyanins [31] and a higher polyphenol content than its pulp [33]. Among the phytochemicals in mango peel reported in the literature, the researchers can find mangiferin, benzophenone derivatives, xanthones, phenolic acids, fatty acids, flavonoids, procyanidins, penta-O-galloyl-glucoside, methyl gallate, tetra-O-galloyl-glucoside, maclurin di-O-galloyl-glucoside, and isoquercitrin [34]. Mango seeds also have a very interesting bioactive composition which includes high concentrations of the major flavonoids and phenolic acids, gallic acid, catechin, chlorogenic acid, caffeic acid, ellagic acid, rutin, quercitrin, quercetin, and kaempferol [34]. Additionally, these seeds are a source of fats, being particularly rich in palmitic, stearic, oleic, and linoleic acids [30].

2.1.7. Passion Fruit

Passion fruit is a tropical fruit with worldwide popularity attributed to its appealing sensorial properties, and its processing for juice results in great quantities of byproducts [104]. Passion fruit peel comprehends about 52% of the total fruit weight and has been shown to have a high content of fiber [36], pectin [40], and phenolic compounds, predominantly isoorientin, and lower concentrations of other flavonoids, such as vicenin, isovitexin, vitexin, orientin, and schaftoside [41][43]. The peels have also been indicated as an excellent source of essential minerals, such as K and Ca [37]. The use of orange passion fruit peel flour in foods (bread, cakes, biscuits, and cereal bars) has likewise been reported to increase their nutritional qualities, contributing to the enrichment of the total dietary fiber, minerals, and bioactive compounds [42]. Besides the peels, passion fruit seeds are also a byproduct with great nutritional value, mainly due to their high lipid content, especially oleic and linoleic acids [37].

2.1.8. Peach

Peach is a fruit highly appreciated for its aromatic characteristics and its richness in dietary fiber, minerals, sugars, organic acids, phenolic compounds, carotenoids, and volatiles [47]. The peach peel contains plenty of polyphenols, such as flavanols, hydroxybenzoic and hydroxycinnamic acids, and flavonols [48]. Furthermore, high carotenoid content was observed in peach peel extracts [46].

2.1.9. Pear

Pear fruit is widely consumed worldwide and can be found in several processed products. It is famous for its many medical functions, such as antidiabetic, anticarcinogenic, and anti-inflammatory properties [45], and various nutrients and bioactive compounds, including sugars, vitamins, organic and fatty acids, amino acids, volatiles, polyphenols, and minerals are attributed to pear fruit [44]. A variety of bioactive compounds has been identified in pear peel, including arbutin, chlorogenic acid, catechin, quercetin, kaempferol, hydroxycinnamoylmalic acids and their ethyl esters, and procyanidins and triterpenes. These compounds were found in pear peel in concentrations approximately 6–20 times higher than those in the flesh of the pear [44].

2.1.10. Pineapple

Pineapple is another highly appreciated tropical fruit in the world due to its nutritional and organoleptic properties. In recent years, the pineapple market has grown significantly, generating huge volumes of byproducts (mainly the core and peel), which have negative economic and environmental impacts [50]. Pineapple core is a rich source of fibers, bromelain [52], and vitamin C [51]. The peel of pineapple contains carbohydrates, proteins, pectin, bromelain, and phenolic compounds, namely gallic acid, catechin, epicatechin, and ferulic acid [52].

2.1.11. Plum

Plum (*Spondias spp.*) has been widely used for medicinal and therapeutic purposes since it is rich in phenolic compounds, namely chlorogenic and gallic acids, resorcinol, and rutin [55]. Moreover, it is a source of ascorbic acid [54]. Plum peel is proved to have high amounts of polyphenols, including flavonoids and anthocyanins, and ascorbic acid [53].

2.1.12. Watermelon

Watermelon is the second-largest fruit crop worldwide and causes a great amount of biowaste, mainly the rind and seeds, that represent an environmental hazard [105]. Watermelon rind is an interesting natural source of citrulline, a non-protein α -amino acid reported to have antioxidant and vasodilatation activity [106], and pectin, a polysaccharide widely used as an additive in the food industry [105]. Additionally, higher levels of phenolic compounds are found in watermelon rind than in its flesh [106]. In turn, watermelon seeds are an excellent source of dietary oils [64], with high levels of linoleic acid and lower concentrations of oleic, palmitic, and stearic acids, as well as minerals (P, K, Na, and Mg) [65]. Enemor, Oguazu, Odiakosa and Okafor [66] also reported a vast vitaminic repertoire in watermelon seeds, namely vitamins A and C and in minor concentrations B1, B2, B3, B6, B9, B12, D, E, and K. A myriad of other bioactive compounds has been also reported in these seeds, mainly sinapic acid, and lower amounts of other phenols, flavonoids, saponin, tannins, cardiac and cyanogenic glycosides, terpenoids, phytosterol, steroids, and phytates [67][107].

2.2. Vegetables

2.2.1. Broccoli

Broccoli is a Brassica vegetable widely consumed worldwide, owing to its health-promoting properties [72][108]. About 60–75% of world broccoli production is wasted during harvesting [70], creating a large number of byproducts, most of which are edible [69]. Broccoli stalks, for instance, constitute an abundant source of pectin, also being rich in phenolic compounds, fructose, glucose, mannitol, polysaccharides, free amino acids, and glucosinolates [69][70].

2.2.2. Cauliflower

Cauliflower is another Brassica vegetable rich in natural antioxidants. It is known to have anticancerous properties due to its abundance in glucosinolates [72][108]. Cauliflower stems and leaves present carbohydrates, protein, fat, and glucosinolates [73]. Further, cauliflower leaves are very rich in dietary fiber and minerals [74].

2.2.3. Potato

Potato is the fourth main crop consumed worldwide and it is an important constituent in the human diet [77].

Potato peels represent about 10% of the total potato waste and are an inexpensive source of valuable bioactive compounds, such as secondary metabolites and cell wall materials, which can be used to functionalize foods or replace

synthetic additives with natural ingredients ^{[109][110]}. Studies have shown that potato peels contain glycoalkaloids, such as α -solanine and α -chaconin, polysaccharides, the phenolic compounds quercetin and rutin, and ferulic, gallic, p-coumaric, caffeic, and chlorogenic acids ^{[110][111]}, which are important precursors for steroid hormones and natural antioxidants, respectively ^[78]. Acylated anthocyanins were identified in the peels of red and purple potato varieties, with pelargonidin, peonidin, and malvidin being the most prominent aglycones ^[79].

2.2.4. Pumpkin

The pumpkin (*Cucurbita spp.*) is a well-known vegetable all over the world and is unquestionably a source of valuable nutrients, such as carotenoids ^[58]. Pumpkin seeds are rich in oil and several health-promoting compounds ^{[57][61]}. The oil extracted from pumpkin seed kernels is rich in protein and fat, including palmitic, stearic, oleic, and linoleic acids. However, the level of accumulation of these fatty acids differs greatly among pumpkin varieties ^[63]. The main proteins previously found in pumpkin seed consist of storage salt-soluble globulins (cucurbitin), albumins, glutelins, and prolamins ^[56]. According to the literature, pumpkin seed kernels also accumulate high levels of minerals such as Fe, Zn, K, Ca, Mg, Mn, Cu, and Na, as well as tocopherol ^{[62][63]}. Pumpkin skins have broad variations in terms of composition and texture, but overall, they are edible and very rich in many bioactive compounds, notably high amounts of carotenoids and polyphenols with broad uses in food, pharmaceutical, and cosmetic industries. Bioactive colorant pigments and skin regeneration formulations are examples of promising applications for pumpkin peel extracts ^[80].

2.3. Dietary Uses of Fruit and Vegetable Waste

The inclusion in diet of fruit and vegetable spare parts, often seeds and peels that are discarded and here generically considered as waste, is not new. Banana peels and blossoms, for instance, have been widely consumed for centuries as a curry, boiled, fried, etc. in Asia (Sri Lanka and India) and some countries in Latin (Brazil) and Central America (Caribbean islands) ^[84]. In Ethiopia, the Indian wild banana *Ensete superbum* (Cliff banana) is the main staple food because this variety is very resistant to severe drought. Moreover, its seeds have been used for generations to treat several health problems such as diabetes, leukorrhea, kidney stones, and dysuria ^[112]. Banana flowers, pseudostem, and unripe fruits are also consumed as vegetables by many indigenous communities ^[113], including rural peoples in India ^[114]. Despite the popularity of the fruit, banana peels are not used in the human diet in most developing countries. Recently, however, the growing concerns of consumers about the sustainability of the planet placed cooking banana peels under social media attention. Hopefully, Nigella Lawson's banana peel curry ^[115] will trigger a change in the way the researchers consider fruit and vegetable waste in diet. Similarly, banana blossoms seem to be a very versatile food to substitute meat proteins, taking into consideration the great number of different potential recipes such as curries, fish and chips, linguini, paella, salads, soups, fish pies, and crab cakes. Beyond the historic use of banana waste in the human diet, which would be the strongest argument that it is a safe procedure, evidence from different studies demonstrates the nutritional and bioactive value of such waste. Boiling bananas, often plantain or cooking banana varieties, increases the phenolic compound content of banana ^[89] because heat softens the vegetable structures, therefore releasing the bioactive compounds into the medium. In this case, banana peel prevents the loss of those bioactives in the water. Similar studies reported an increase in phenolic content during thermal processing of banana peel ^{[114][116]}.

For most people, the hairy skin of kiwi fruit is not very appetitive to eat. However, not only are the peels edible, eating skin-on kiwi greatly increases nutrient intake, namely of fibers, vitamins C and E, and a great number of bioactive compounds ^{[29][117]}. Consumption of whole SunGold kiwifruit (including the skin), for instance, was shown to increase the fiber, vitamin E and folate contents by 50, 32, and 34%, respectively ^[118]. To facilitate the ingestion of kiwi skin, the hairs can be easily removed by rubbing the fruit, scrubbing it with a vegetable brush, or scraping it lightly with a spoon.

Tannins are widely present in many fruits, particularly in their wasted parts, such as citrus and banana peels. This abundance is the main reason why consumers reject those parts because tannins confer high astringency and unpleasant flavors. When present in lower amounts, however, tannins are more easily tolerated by consumers, as occurs with the proanthocyanidins present in grape skins. Different strategies, however, can be used to mitigate the high abundance of tannins, such as sweetening to obtain marmalades and jams, or fermentation to obtain beverages, such as tepache ^[49]. This is a traditional Mexican beverage that is obtained by fermentation of different fruits and fruit waste, according to the region where it is produced. Pineapple rinds and tamarind, banana peels, corn husks, crushed corn, persimmon, apple, jujube, pomegranate, plum, cranberry, sour cherry, soursop, mango, orange, and papaya are among the tepache varieties in traditional Mexican food folklore ^[49]. Although there are not many studies in the literature about these traditional fermented beverages, it is known that the use of fruit during the fermentation process of beverages such as beer enhances the content of bioactive compounds, in particular polyphenols and carotenoids ^[14]. Acetic fermentation to obtain vinegar is also a popular process to give additional uses to many fruit wastes ^[10]. Traditionally associated with wine, vinegar can be produced from many fruit wastes such as the peels and cores from apple, kiwi fruit, pineapple, pear,

mango, melon, watermelon, etc. In simple terms, any fruit and its waste can be fermented to obtain vinegar enriched with different cocktails of nutrients and bioactive compounds. In this respect, Sandor Katz is carrying out very relevant work unveiling ancient techniques behind fermentations that everyone can use at home ^[119].

Cucurbita moschata Duchesne (squash and pumpkin varieties) is a plant food highly appreciated for the content of nutrients and bioactive compounds, including polyphenols and carotenoids. Its peel (including the rind layers immediately below the peel) are particularly rich in pectins which can be used in various food processing operations due to their gelling properties. Pectins are also used as thickening agents and stabilizers in jams, jellies, etc. ^[81]. Pumpkin peel therefore has many industrial applications, but it can also be very useful for consumers even with minimal cooking procedures. Although ripe pumpkin peel is very hard to eat, it can be easily softened by different cooking procedures, such as boiling, roasting, frying, or baking, for use in pies and cakes. **Table 2** presents selected examples from the literature showing cooking procedures to incorporate fruit wastes in diet.

Table 2. Examples of possible uses and cooking procedures for several fruit and vegetable wastes.

Fruit or Vegetable Waste	Suggested Cooking Procedure	Ref.
Apple peel	Cookies: peels were blanched in hot water for 30 s, washed and dried (48 h, 60 °C), ground, and used to make cookies.	^[120]
Citrus peel	Jam: washed and crushed peels were mixed with water to form a puree, and then sugar, pectin, and citric acid were added to obtain a jam-like texture.	^[121]
Passion fruit peel	Cookies: peels were immersed in water (100 °C, 15 min) and cooled on ice, epicarp was separated with a spoon, dried (60 °C), ground, and used to make cookies.	^[122]
Pineapple core	Pineapple dried core: core was cut into small pieces and dried in a microwave oven.	^[123]
	Pineapple core fiber was extracted and incorporated into dough and steamed bean.	^[124]
Pineapple peel	Beef marination: the peel was washed, cut, mashed with a blender, and filtered; the juice was then used to marinate beef.	^[125]
	Gluten-free muffins: peels were sanitized with 100 ppm chlorinated solution for 15 min, dried for 8 h at 60 °C, and milled to obtain flour.	^[126]
Plum peel	Marmalade: peels were mixed with water and filtered to make a puree, and then sugar syrup, pectin, and citric acid were added to obtain marmalade.	^[127]
	Jam: washed and crushed peels were mixed with water to form a puree, and then sugar, pectin, and citric acid were added to obtain a jam-like texture.	^[128]
Potato peel	Potato peel chips: peels were dried, milled, and sieved to obtain flour, then mixed with wheat flour to make deep-fried chips.	^[129]
	Potato peel dough: peels were dried at 50 °C in an oven for 48 h, ground in a mixer grinder to make flour, mixed with wheat flour, and incorporated into dough.	^[130]
	Gluten-free bread: peels were sanitized with sodium hypochlorite solution, dried at 70 °C for 24 h in a forced-air oven, and ground using a blender; the flour obtained was used to produce gluten-free bread.	^[131]
Pumpkin rind and seeds	Bread: rinds and seeds were dried in an oven at 60 °C for 24 h and ground using a grinder to obtain a fine particle size, then the flour obtained was incorporated into bread.	^[132]
Watermelon rind	Marmalade: rind was mixed with water and filtered to make a puree, and then sugar syrup, pectin, and citric acid were added to obtain marmalade.	^[133]
	Watermelon rind flour: rind was cut into small chips, dried at 60 °C for 48 h, and milled into powdered flour to use in cakes.	^[134]
Watermelon seeds	Watermelon snacks: seeds were ground in a mixer grinder into a fine powder and sieved to obtain uniform size distribution of the grains; the flour obtained was mixed with rice and corn flour and used to make snacks.	^[135]

Many more examples of home food applications and recipes for fruit and vegetable waste could be included. This would be, however, a very long list that obviously cannot be included here. Instead, the selected examples constitute a flavor of the bioactive potential that is being neglected in the fruit and vegetable waste that is discarded in kitchens (**Figure 2**).

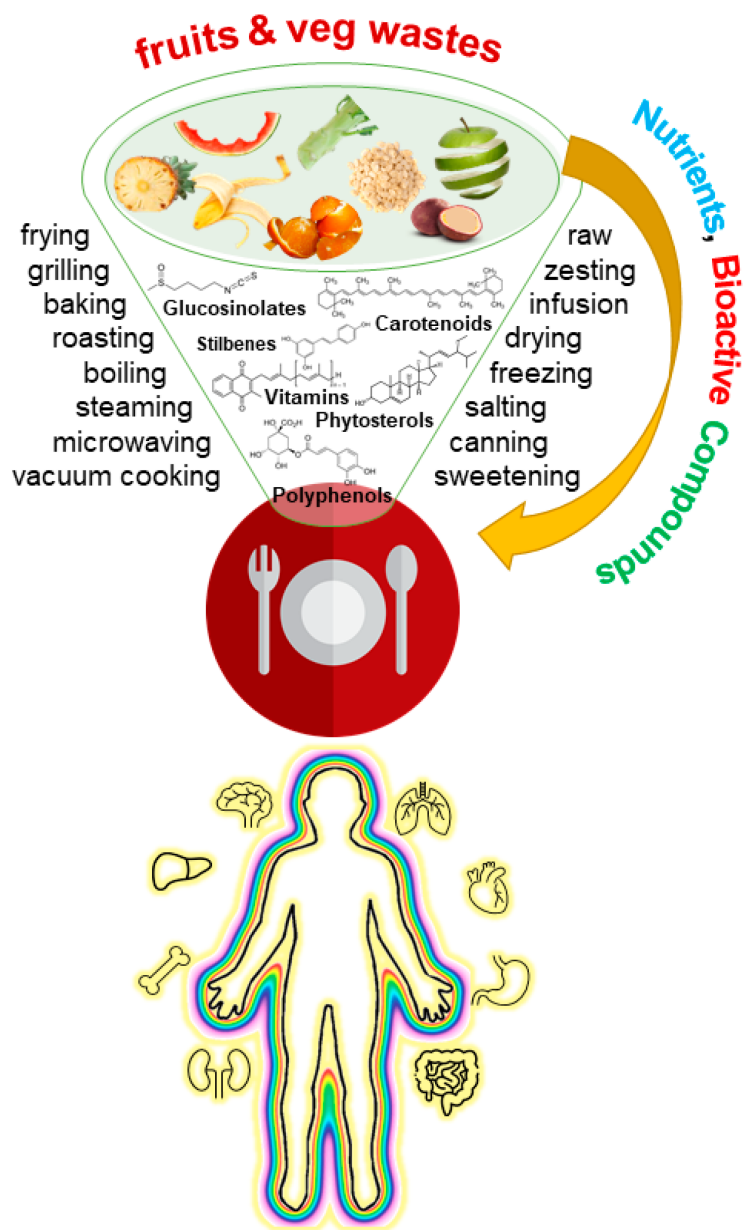


Figure 2. Integrative overview of the rationale behind fruit and vegetable waste cooking to include important molecules with reported bioactive effects in diet.

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