

## REVIEW

# Biologically active components in by-products of food processing

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## Abstract

Food by-products happen at various stages of production and processing at home and on commercial scales. In the recent years, because of the fast-growing food companies and production, food processing by-products have gained a lot of interest and attracted many technical and health professionals as well as policy makers internally and internationally. Also, concerns are increasing about food by-products due to their ecological and environmental impact on the planet. This is particularly of concern when large companies emit. Large quantities of food by-products are thrown into environment in which they can be exploited technically, medicinally, and pharmaceutically. This is due to their chemical component and biologically active compounds of the by-products. Therefore, this systematic review focuses on the food by-product biological compounds present in different parts of the food products, particularly in some common foods such as fruits, vegetables, cereals, dairy products, meat, eggs, nuts, coffee, and tea. Moreover, the review also explains the kind of biologically active compounds and their quantity not just in edible foods, but also in part and types of the by-product which then can be reused and recycled into different processes in order to extract and get benefit from.

## KEYWORDS

antioxidants, food by-products, food processing, phytochemicals

## 1 | INTRODUCTION

There are rapidly growing scientific data and literature focusing on the role of food processing secondary and by-products in relation to human well-being. Coincidentally, there is an increase in the consumers' information regarding noncommunicable diet-associated diseases (Chernukhaa & Fedulova, 2015). Thus, the demand for nonchemical, natural, safe, and health-improving food components is also growing (Schieber, Stintzing, & Carle, 2001). Large quantities of agricultural secondary or by-products generated after food processing have become the main issue concerning food industry worldwide, since they could lead to environmental including pollution (soil, water, air). Furthermore, the disposal of agricultural by-products could cost huge amount to treat under certain governmental regulations (Gowe, 2015).

Additionally, it is no longer pragmatic to discard by-products therefore; utilization of by-products has become an alternative method to overcome this issue (Lafarga & Hayes, 2014; Zhao, Chen, & Du, 2012). Particularly, when food processing by-products have considerable quantity of valuable and favorable raw bioactive functional compounds, therefore they can be useful for both technological and pharmaceutical purposes (Azyyati & Yen, 2014; Schieber et al., 2001).

For recovery of biologically active compound in food by-products, different conventional methods including solvent-based extraction have been used. However, due to more demand for eco-friendly, cheap, and high-efficiency methods, novel techniques are superior to conventional methods (Gençdağ, Görgüç, & Yılmaz, 2020) and novel methods have been studied and examined. The methods used include membrane-based technologies including microfiltration,

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ultrafiltration, and nanofiltration (Castro-Muñoz, Conidi, & Cassano, 2019), ultrasound-assisted extraction (Sabater, Sabater, Olano, Montilla, & Corzo, 2020), microwave-assisted extraction (Casazza, Pettinato, & Perego, 2020), electrotechnologies, ultrasound, high hydrostatic pressure, nanotechnology, and pressurized fluid (Zhu et al., 2020). The aim of this review was to present and give an overview about the most common biologically active compound present in a wide range of food products. Furthermore, the review also presents the by-product bioactive compound in different food products such as milk, eggs, meat, cereals, fruit and vegetable, herbs and spices, coffee and tea, honey and sugar, and additives. Moreover, health and pharmaceutical benefits of the bioactive compounds will be presented (Table 1).

## 2 | METHODOLOGY

This systematic review was done through collecting data from databases such as PubMed and Web of Science as well as articles

available in Google Scholar. The exclusion area included articles published before 1980, non-peer-reviewed articles, articles published in other languages than English, and nonoriginal articles including letters, editorial conference summaries, and paper without abstract. Therefore, only articles met these requirements were accepted.

## 3 | FOOD PROCESSING BY-PRODUCTS

### 3.1 | Fruits

Fruits are one of the food materials that undergo industrial processing which could lead to various waste materials in different forms and shapes during pre- and postharvesting process in growing, preparation, and processing (Joshi & Devrajan, 2007). As a result of that diversity, the by-product left is extremely dissimilar because of the difference in the fruits various industrial processes and producing different products. Some fruits result in 25%–30% by-product or nonedible waste products (Ajila et al., 2009). However, less waste

**TABLE 1** Estimate of by-products in the food industry

Industrial sector	Amount of waste (1,000 ton)	By-products (%)
Production, processing, and preserving of meat and meat products	150	2.5
Production and preserving of fish and fish products	8	3.5
Production and preserving of fruits and vegetables	279	4.5
Manufacture of vegetable and animal oils and fats	73	1.5
Dairy products and ice cream industry	404	2
Production of grain and starch products	245	1.5
Manufacture of other food products	239	2
Drink industry	492	2
Total	1,890	2.6

**TABLE 2** Chemical composition of by-products of various fruits

By-products	Moisture	Protein	Fat	Minerals	Fiber	Carbohydrate
Apple pomace	-	2.99	1.7	1.6	16.1	17.3
Mango seed kernel	8.2	8.5	8.8	3.6	-	74.4
Jack fruit (inner and outer portions)	8.5	7.50	11.8	6.5	30.7	14.1
Jack fruit seeds	64.5	6.6	0.4	1.2	1.5	25.8
Jack seed flour	77	2.6	0.2	0.7	1.0	18.1
Passion fruit peel	81.9	2.5	0.1	1.4	5.0	-
Banana peel	79.2	0.8	0.7	2.1	1.7	5.0
Sweet orange seeds	4.0	15.8	36.9	4.0	14.0	-
Watermelon seeds	4.3	34.1	52.6	3.7	0.8	4.5
Watermelon seeds	6.8	21.0	33.0	4.0	30.0	-
Pumpkin seeds	6.0	29.5	35.0	4.5	12.0	12.5
Banana central core	93.1	0.3	0.03	1.0	0.6	1.20
Outer hard fibrous sheath	91.9	0.1	0.06	0.98	1.8	2.4
Press juice from stem	98.6	0.05	-	0.6	-	0.4

**TABLE 3** Total phenol content (mgGAE g<sup>-1</sup>) of vegetable by-products using different solvents

Raw material	Water	Methanol	Ethanol	Acetone	Hexane
Artichoke	42.75 ± 12.17	95.65 ± 8.24	88.15 ± 4.99	102.33 ± 6.19	36.65 ± 5.87
Asparagus	89.40 ± 5.07	69.43 ± 7.06	60.14 ± 5.85	113.65 ± 17.73	29.33 ± 4.36
Tomato	12.15 ± 0.83	37.29 ± 2.08	42.00 ± 6.19	49.61 ± 9.52	30.24 ± 4.76
Broccoli	29.87 ± 1.58	25.58 ± 2.51	28.31 ± 1.69	36.18 ± 1.89	33.45 ± 2.32
Cucumber	18.41 ± 2.68	27.26 ± 1.80	16.96 ± 2.16	20.52 ± 2.59	26.71 ± 5.21
Endive	34.01 ± 6.79	17.18 ± 2.24	16.12 ± 2.48	23.66 ± 0.93	23.44 ± 2.46
Chicory	13.56 ± 1.81	25.51 ± 3.11	21.54 ± 3.58	14.16 ± 1.45	12.30 ± 1.80

agribusiness has become a global need nowadays to overcome waste problem.

According to the fruit waste part; peel, seed, and stones produced after fruit processing, they could be importantly utilized as sources of many bioactive components for agroindustry to role in the aspect and transform these by-products into valuable products (Tuchila, Jianu, Rujescu, & Butur, 2008). In a study about bioactive compounds, it was found that the mango peel and seed contained the highest quantity of bioactive compound. The peel included 5.997 mg of gallic acid/g of fresh weight (fw), 4.455 mg of quercetin/g fw, and 47.97% DPPH-free radical scavenging activity at the concentration of 322 mg/ml, while the seed presented 37.279 mg of gallic acid/g, 35.954 mg of quercetin/g on fw basis, and 93.4% of DPPH-free radical scavenging activity at the concentration of 307 mg/ml (Ayala-Zavala, Rosas-Domínguez, Vega-Vega, & González-Aguilar, 2010). In another study regarding the phenolic and antioxidant in some fruits including mango, longan, jackfruit, and avocado, following different analytical method ABTS (2,2-azinobis-3-ethylbenzothiazoline-6-sulfonic acid), FRAP (ferric-reducing antioxidant power), and FCR (Folin-Ciocalteu reagent) have been used. The research found that the seeds of these fruits contained more antioxidant capacity and phenolic content than the pulp. The ABTS, FRAP, and FCR values for the seeds of mango, longan, avocado, and jackfruit were as follows:

**TABLE 4** Total dietary fiber content of different vegetable by-products

By-products	Quantity (100 g dry weight basis)
Cabbage outer leaves	40.5
Carob	53.0
Carrot	48
Cauliflower	65.0
Pepper	80.4
Peas, green-frozen	82.3

762, 448, 236.1, and 7.4 μmol of ascorbic acid/g; 2,572, 1,388, 1,484, and 2.8 μmol of gallic acid equivalents/g; and 117, 62.6, 88.6, and 27.2 mg of gallic acid equivalents/g, respectively. The ABTS, FRAP, and FCR values for the pulp of mango, longan, avocado, and jackfruit were as follows: 7.2, 3.7, 4.9, and 3.0 μmol of life-protecting phytochemicals and antioxidants (Galali, Aziz, & Ali, 2017). Furthermore, depending on the type of the fruit and part of the fruit, high percentage of the antioxidants can be obtained such as vitamins C and E, phenolic compounds including phenyl-propanoids and flavonoids, and/or carotenoids such as lycopene. Similar to the entire tissue, by-products are rich in phytochemical, antioxidant, and antimicrobial

**TABLE 5** Elements in fruit by-products

	Al mg/kg	As mg/kg	B mg/kg	Ba mg/kg	Ca mg/kg	Cd mg/kg	Co mg/kg	Cr mg/kg	Cu mg/kg	Fe mg/kg	Hg mg/kg
Apricot	0.9	<0.05	0.10	0.014	3.6	0.002	0.029	0.6	0.04	2.3	<0.05
Banana	0.6	<0.05	0.06	0.005	1.7	<0.001	0.01	0.03	0.4	0.2	<0.05
Clementine	1.0	<0.05	0.13	0.014	16.5	<0.001	<0.008	0.005	0.9	0.1	<0.05
Lemon	3.1	<0.05	0.04	0.021	13.0	<0.001	<0.006	0.005	0.6	0.1	<0.05
Melon	3.4	<0.05	0.03	0.001	3.70	<0.001	0.010	0.001	0.8	0.1	<0.05
Orange	0.3	<0.05	0.05	0.016	17.	<0.001	0.01	0.02	0.05	0.2	<0.05
Peach	0.6	<0.05	0.04	<0.002	1.2	0.001	0.02	0.001	1.3	0.2	<0.05
Pear	0.1	<0.05	0.06	0.001	0.9	<0.001	0.007	0.006	0.4	0.08	<0.05
Pineapple	4.8	<0.05	0.02	0.009	3.0	<0.001	0.005	0.001	1.9	0.07	<0.05
Watermelon	2.0	<0.05	0.03	0.006	1.5	0.001	0.01	0.2	0.004	0.8	<0.05

Abbreviations: Al, aluminum; As, arsenic; B, boron; Ba, barium; Ca, calcium; Cd, cadmium; Co, cobalt; Cr, chromium; Cu, copper; Fe, iron; Hg, mercury; K, potassium; Li, lithium; Mg, magnesium; Mn, manganese; Mo, molybdenum; Na, sodium; Ni, nickel; Pb, lead; Se, selenium; Sn, Tin; Sr, strontium; V, vanadium; Zn, zinc.

compounds than the end products (Ayala-Zavala et al., 2010). Therefore, recently the modern technology has focused on the utilization and exploitation of these by-products in the production of new useful product with high technical and pharmaceutical properties as food additives and supplementation, since they possess many benefits which include antiviral, antibacterial, cardioprotective, and antimutagenic properties (Djilas, Canadanovic-Brunet, & Cetkovic, 2009). Despite having this usefulness, there is no comprehensive utilization and exploitation due to lack of understating the pharmaceutical and economic benefits, so there is an important opportunity to ascorbic acid/ g: 36.6, 41.5, 9.6, and 6.8  $\mu\text{mol}$  of gallic acid equivalents/g and 2.4, 1.6, 1.3, and 0.90 mg of gallic acid equivalents/g, respectively (Soong & Barlow, 2004). Another research noticed that the peel and seed of "Uba" mango had a total phenolic content of 0.0572 and 0.08254 mg/g on dry matter basis. These values are 4.6 and 7.3 times more than those in the pulp (Ribeiro, Barbosa, Queiroz, Knödler, & Schieber, 2008). It has been found that the phenolic compound of muscadine grapes in the seed was the highest followed by skin and pulp. Seventeen-base units named isoprene. Terpenes or terpenoids are powerful against microbes. The peel and seed of avocado exhibited antimicrobial activity against some gram-negative and gram-positive bacteria and yeast. It was also observed that the seed and peel extract of "Hass" avocado showed a minimum inhibitory activity with 104.2  $\mu\text{g}/\text{ml}$  against *Salmonella enteritidis* and *Zygosaccharomyces bailii* (Raymond Chia & Dykes, 2010). Lemon extracts were used in dairy products and improved the shelf life of mozzarella cheese. Pomegranate peel extracts showed antimicrobial activity against *Staphylococcus aureus* and *Bacillus cereus* in chicken and meat and increased shelf life by 3 weeks; compounds were identified in muscadine grapes. The compounds identified in seeds included hydrolyzable tannins, flavan-3-ols and condensed tannins, ellagic acid derivatives, and quercetin rhamnoside. The skin contained hydrolyzable tannins and flavonoids, including anthocyanin 3,5-diglucosides, quercetin, myricetin, and kaempferol glycosides ( Sandhu & Gu, 2010). It has been found that the most common

phenol compounds in grape seeds were seemed to be flavan-3-ols; most of them are gallic acid gallate and catechin. The skins were mostly flavonols, that is, quercetin and myricetin. Determination of anthocyanins in the berry skin by ultra-high-performance liquid chromatography discovered twenty derivatives of malvidin, delphinidin, petunidin, cyanidin, and peonidin (Pantelić et al., 2016). Fruits by-products are also important for antimicrobial activity against some pathogenic, spoilage bacteria, and yeasts. The most abundant studied antimicrobials are essential oils. Essential oils are natural and volatile having strong odor produced by plants (Bakkali, Averbeck, Averbeck, & Idaomar, 2008). One of them is terpenes. They composed of a combination of 5-carbon and controlled rancidity during storage. Antibacterial activity of grapes extracts was studied. They showed positive activity against some pathogenic bacteria. Therefore, fruit by-products are promising source of antimicrobial agents (Amaral, Ekins, Richards, & Knowles, 1998).

Fruit by-products are also a good source of antioxidant that can be used as antibrowning agent that could happen to free cut fruits and reduced the quality of the products. It has been reported that low percentage of ascorbic acid reduced the browning reaction in fresh-cut peaches and apple slices and fresh-cut pineapple. Also, extracts from Palo Fierro rich in antioxidants reduced the browning of apple juice.

Fruit by-products are a good source of natural colorant and pigments due to high stability, purity, availability, and low cost particularly when the synthetic colorants are publically rejected due to health concerns. One of the common colorants that is extracted from different fruit by-products is grape pomace (Stintzing & Carle, 2004) blueberry (Bobinaité et al., 2016) and some other guajiru, jambolao, jussara, and acai (Sousa De Brito et al., 2007).

Fruit by-products are significantly rich in bioactive dietary fibers which are crucial in prevention in many diet-associated diseases (Zhu, Du, Zheng, & Li, 2015). Dietary fiber and fiber-rich by-products of food processing present high technical and pharmaceutical properties. Thus, they have been supplemented to many food products

K mg/kg	Li mg/kg	Mg mg/kg	Mn mg/kg	Mo mg/kg	Na mg/kg	Ni mg/kg	Pb mg/kg	Se mg/kg	Sn mg/kg	Sr mg/kg	V mg/kg	Zn mg/kg
29.8	<0.005	1.3	0.31	0.02	0.08	2.8	0.04	<0.1	<0.25	0.01	0.007	0.08
51.7	<0.005	4.3	0.08	0.01	0.08	2.5	0.08	<0.1	<0.25	0.03	<0.002	0.4
16.7	<0.005	2.1	0.02	0.003	0.2	1.2	0.1	<0.1	<0.25	0.1	<0.002	0.9
19.7	<0.005	1.6	0.03	<0.001	0.4	0.4	0.3	<0.1	<0.25	0.07	<0.001	1.1
37.6	<0.005	3.6	0.02	<0.001	1.1	0.5	0.1	<0.1	<0.25	0.02	<0.001	0.9
11.8	<0.005	1.6	0.03	0.007	0.1	2.4	0.02	<0.1	<0.25	0.23	<0.001	0.05
19.0	<0.005	1.2	0.01	<0.002	0.1	3.2	1.50	<0.1	<0.25	0.02	<0.002	8.4
7.8	<0.005	0.6	0.01	<0.002	0.2	0.9	0.3	<0.1	<0.25	0.01	<0.002	1.2
12.9	<0.005	1.3	0.16	<0.001	0.08	0.5	0.05	<0.1	<0.25	0.02	<0.001	1.5
17.1	<0.005	1.6	0.16	0.007	0.08	2.2	0.01	<0.1	<0.25	0.01	0.002	0.02

**TABLE 6** Chemical composition and bioactive compounds in some vegetable by-products

	Ash	Organic matter	Crude protein	Neutral detergent fiber	Neutral detergent solubles	Acid detergent fiber
Sugar beet leaves	21.0	78.9	21.9	42.3	57.8	21.1
Cauliflower leaves	13.7	86.4	17.0	27.5	72.5	19.4
Black chick pea plant	9.8	90.2	13.6	46.4	53.6	38.2
Cabbage leaves	15.8	84.2	19.9	33.7	66.3	22.6
Pea vines	10.0	89.9	11.8	60.0	40.0	49.9
Radish leaves	22.1	77.9	19.4	27.9	72.1	21.9
Summer squash vines	23.3	76.8	13.9	41.1	58.9	40.4
Baby corn husk	5.2	94.8	11.6	60.9	39.1	28.8
Carrot	8.2	91.8	9.9	9.0	91.0	8.0
Ensiled pea vines	9.0	91.0	13.1	59.0	41.0	49.0
Potato	4.8	95.2	9.5	-	-	-
Snow peas	5.2	94.8	23.2	23.1	76.9	14.4
Sugar beet pulp	7.3	92.3	10.0	45.8	54.2	23.1
Tomato pomace	6.0	94.0	22.1	63.0	37.0	51.0

(Elleuch, Bedigian, Roiseux, & Besbes, 2011). In a study about the percentage of neutral dietary fiber, acid dietary fiber cellulose, hemicelluloses, and lignin based on 100 g dry matter, it was found that the percentages of dietary fiber were up to 63% (Table 2; Verma & Joshi, 2000).

Protein is also another component of the fruit by-products particularly seed and kernel flour which can be an inexpensive source to be exploited for different purposes. Different fruits such as papaya, apple, watermelon, guava, orange, prickly pear, apricot, and paprika discovered to contain different quantity of various amino

acids including leucine, isoleucine, methionine, phenylalanine, lysine, threonine, tyrosine, and valine. This adds additional nutrition value to the by-products (Salem & Abd El-Ghany, 2012).

### 3.2 | Vegetables

Vegetable by-products composed of different parts: peels, seeds, stones, and leaves. They could be source of different materials such as antioxidants such as vitamins C and E, phenolic compounds

**TABLE 7** Elements in vegetable by-products

	Al mg/kg	As mg/kg	B mg/kg	Ba mg/kg	Ca mg/kg	Cd mg/kg	Co mg/kg	Cr mg/kg	Cu mg/kg	Fe mg/kg	Hg mg/kg
Aubergin	3.4	<0.05	0.03	0.006	2.6	<0.001	<0.004	0.001	0.42	0.07	<0.05
Broccoli	0.07	<0.05	0.06	0.01	14.0	<0.001	<0.006	0.002	0.3	0.1	<0.05
Cabbage	0.09	<0.05	0.04	0.006	7.9	<0.001	0.004	0.001	0.1	0.08	<0.05
Cauliflower	0.1	<0.05	0.03	0.006	4.2	<0.001	0.005	0.000	0.3	0.08	<0.05
Clementine	1.0	<0.05	0.13	0.01	16.5	<0.001	<0.008	0.005	0.9	0.1	<0.05
Courgette	0.1	<0.05	0.02	0.002	2.3	<0.001	0.003	0.002	1.6	0.08	<0.05
Cucumber	2.2	<0.05	0.02	0.004	3.7	<0.001	<0.002	0.001	0.05	0.05	<0.05
Endive	1.0	<0.05	0.01	0.000	3.6	<0.001	0.002	0.025	0.08	0.1	<0.05
Fennel	1.7	<0.05	0.02	0.007	5.4	<0.001	0.018	0.080	0.35	0.5	<0.05
Lemon	3.1	<0.05	0.04	0.02	13.5	<0.001	<0.006	0.005	0.69	0.10	<0.05
Lettuce	3.0	<0.05	0.01	0.005	6.9	<0.001	0.026	0.038	0.3	0.4	<0.05
Onion	0.7	<0.05	0.07	0.02	9.2	<0.001	0.004	0.001	0.5	0.1	<0.05
Pepper	0.3	<0.05	0.01	0.001	0.6	<0.001	<0.004	<0.001	0.8	0.09	<0.05
Potato	5.48	<0.05	0.07	0.017	4.8	<0.001	0.012	<0.001	0.4	0.1	<0.05
Tomato	0.4	<0.05	0.01	0.000	1.2	<0.001	0.003	0.001	0.3	0.07	<0.05
Carrot	1.0	<0.05	0.03	0.021	6.2	<0.001	<0.004	0.004	0.1	0.1	<0.05

Hemicellulose	Cellulose	Total sugar	Albumin	Globulin	Prolamin	Glutelin	Total phenol
21.2	11.4	24.9	60.6	12.7	12.0	14.7	2.9
8.1	15.2	18.6	62.4	12.9	9.1	15.6	5.9
8.3	25.3	14.0	43.5	13.5	27.6	15.5	3.2
11.1	13.7	20.6	54.3	16.2	8.2	21.3	5.9
10.0	36.8	6.4	56.9	12.4	7.9	22.7	4.5
5.9	14.9	9.5	61.0	13.7	11.4	13.8	6.9
0.7	16.9	7.8	69.8	14.8	2.8	12.6	3.7
32.1	24.4	-	-	-	-	-	-
1.0	7.0	-	-	-	-	-	-
10.0	34.0	-	-	-	-	-	-
-	-	-	-	-	-	-	-
8.7	21.6	-	-	-	-	-	-
22.7	-	-	-	-	-	-	-
12.0	12.0	-	-	-	-	-	-

including phenyl-propanoids and flavonoids, and/or carotenoids such as lycopene can be found (Ayala-Zavala et al., 2010).

Vegetable by-products are important sources of phenolic compounds that present and can be extracted using different solvents. Various by-products seemed to contain different bioactive compounds. Asparagus waste seems to have the highest phenolic compounds, and tomato showed the lowest phenolic compounds (Table 3; Peschel et al., 2006). It was found that using acetone solvent could be very powerful to extract phenolic compounds. It has been reported that caffeic acid derivatives are

the major component in artichoke by-products with a prevalent range of caffeoylquinic acid derivatives with chlorogenic acid (5-O-caffeoylquinic acid) as the most important of these derivatives. Some other phenolic compounds such as the flavonoids apigenin and luteolin (both glucosides and rutinosides) as well as different cyanidin caffeoylglucoside derivatives were determined (Llorach, Espín, Tomás-Barberán, & Ferreres, 2002). Furthermore, by-product from lettuce showed the presence of hydroxycinnamic acids and flavonoids. The flavonoids made of flavones (luteolin derivatives) and flavonols (quercetin derivatives), whereas

K mg/kg	Li mg/kg	Mg mg/kg	Mn mg/kg	Mo mg/kg	Na mg/kg	Ni mg/kg	Pb mg/kg	Se mg/kg	Sn mg/kg	Sr mg/kg	V mg/kg	Zn mg/kg
20.7	<0.005	1.8	0.02	0.001	0.30	0.2	0.1	<0.1	<0.2	0.02	<0.001	0.49
27.46	<0.005	4.3	0.02	0.008	3.2	0.2	0.06	<0.1	<0.2	0.08	<0.001	0.3
21.1	<0.005	3.0	0.02	0.002	3.4	0.5	0.04	<0.1	<0.2	0.04	<0.001	0.2
23.0	<0.005	2.8	0.02	0.003	2.8	0.7	0.03	<0.1	<0.2	0.02	<0.001	0.2
16.7	<0.005	2.1	0.02	0.003	0.2	1.2	0.1	<0.1	<0.25	0.1	<0.002	0.9
18.5	<0.005	1.9	0.01	0.002	0.1	0.6	0.07	<0.1	<0.2	0.01	<0.001	1.1
12.4	<0.005	1.8	0.01	0.002	1.1	0.07	0.01	<0.1	<0.25	0.02	<0.001	0.06
12.4	<0.005	1.3	0.03	0.001	0.1	0.3	0.02	<0.1	<0.25	0.00	<0.001	0.08
21.6	<0.005	1.3	0.09	0.005	5.5	0.3	0.1	<0.1	<0.2	0.03	0.001	0.5
19.7	<0.005	1.6	0.03	<0.001	0.4	0.4	0.3	<0.1	<0.2	0.07	<0.001	1.1
30.1	<0.005	1.6	0.08	0.001	1.2	0.2	0.1	<0.1	<0.25	0.02	<0.001	1.1
12.2	<0.005	1.7	0.02	0.002	0.9	0.5	0.1	<0.1	<0.2	0.05	<0.001	0.8
15.8	<0.005	1.1	0.01	<0.001	0.1	0.77	0.09	<0.1	<0.2	0.00	<0.001	0.7
45.3	<0.005	3.3	0.03	<0.002	0.35	0.2	0.1	<0.1	<0.2	0.01	<0.002	0.7
9.9	<0.005	0.6	0.01	0.001	0.2	0.6	0.04	<0.1	<0.2	0.00	<0.001	0.3
14.2	<0.005	2.2	0.03	0.003	8.7	0.1	0.02	<0.1	<0.25	0.03	<0.001	0.1

by-products from chicory made of only of kaempferol derivatives (Llorach, Tomás-Barberán, & Ferreres, 2004). Cauliflower by-products also showed to contain phenolic compounds. It has been stated that cauliflower by-products contain flavonoids and hydroxycinnamic acids (caffeic acid and sinapic acid). Flavonols such as kaempferol and quercetin with sinapic acid and glucose seemed to be the major phenolics available (Llorach, Espín, Tomás-Barberán, & Ferreres, 2003).

Dietary fiber contributes to the major part of the discarded by-products of vegetables. It has been studied that the total dietary fiber content in vegetable by-products ranges from 40% to 82% including all the types of soluble and insoluble dietary fibers (Table 4; Goñi & Hervert-Hernández, 2011). They impart a substantial quantity of biologically active compounds including polyphenols and carotenoids associated with the fiber in the human digestive system. So, phytochemicals participate in the body well-being through dietary fibers. Therefore, phytochemicals can be deemed as dietary fiber components in the perception of similarity in their resistance digestibility in the digestive tract. It can be seen that the by-products are a rich sources of dietary fiber and other bioactive compounds and values can be added to it because of that (Saura-Calixto & Serrano, 2007).

Regarding the elements, there is dissimilar amount present in vegetable by-products. But it can be concluded that fruit and vegetable wastes possess high level of organic material that can be utilized for different purposes (Asquer, Pistis, & Scano, 2013), particularly if they are used as a feed to livestock which could be a balanced diet in terms of micro-, macro-, and trace elements (Table 5).

Vegetable by-products contain various chemical and bioactive compounds which can be used in different ways. Ash content was high in summer squash vines (23.3%), whereas the lowest percentage (4.8%) was found in potato (Table 6). Moreover, lowest organic matter was found in summer squash vines (77.8%) and the highest was found (94.8%) in baby corn husk. Snow pea protein showed

the highest percentage of 23.2%. In addition, cellulose in pea vines and hemicellulose in baby corn husk were found with highest percentage by 36.8 and 32.1, respectively. As it is the source of table sugar, sugar beet leaves showed the highest percentage of sugar by 24.9. Regarding specific proteins, albumin in cauliflower leaves, globulin in cabbage leaves, prolamin in black chickpea plant, and glutelin in pea vines were found with 62.4, 16.2, 27.6, and 22.7, respectively. Finally, percentage of the phenolic content of the radish leaves seemed to be the highest by 6.9% comparing to others (Table 7; Wadhwa & Bakshi, 2013). The above data show that the vegetable by-products are rich in bioactive compounds and can be useful pharmaceutically.

### 3.3 | Coffee

A large quantity of by-products are accumulated during the process of green bean coffee production which is estimated to be around 50% (Mussatto, Carneiro, Silva, Roberto, & Teixeira, 2010). There are different by-products that are generated after green coffee bean production according to the method used. The by-product of dry technique is primarily husk which includes the dried skin, pulp, and parchment by 0.18 ton per ton (Esquivel & Jiménez, 2012; Murthy & Madhava Naidu, 2012). The by-product of wet technique is mainly coffee pulp and the coffee silver skin, and the last by-product is spent coffee ground after brewing process.

The chemical composition of coffee by-products of different studies from 2000 to 2009 is presented in Table 8. The total carbohydrate is between 35 and 72.3, and total fiber is ranged from 24 to 43. Protein content is ranged from 5 to 11, but the lowest content is mineral which is up to 10%.

Table 9 shows the procyanidin and flavonol content of coffee by-product in Arabica and Robusta from Mexico, India, and China. The lowest amount of flavonols, 5 µg/g, was unraveled in Robusta

**TABLE 8** Bioactive compounds of coffee by-products

Components	(Pandey et al., 2000)	(Brand et al., 2001)	(Ferraz & Silva, 2009)	(Gouvea, Torres, Franca, Oliveira, & Oliveira, 2009)	(Bekalo & Reinhardt, 2010)	(Shenoy et al., 2011)	(Murthy & Naidu, 2012)	(Murthy & Madhava Naidu, 2012)	(Srinivas Murthy, Navya, & Murthy Pushpa, 2013)
Total carbohydrate	57.8	35.0		72.3	-	-	-	-	-
Total fiber	-	30.8		-	-	-	24 ± 5.9	43 ± 0.5	24.0
Hemicellulose	-	-	23.8	11.0	29.7	28.0	7.0 ± 3.0	-	-
Cellulose	-	-	23.1	16.0	24.5		43 ± 8.0	-	43.0
Lignin	-	-	28.3	9.0	23.7	72.0	9.0 ± 1.6	-	9.0
Pectin	12.4	-	-	-	-	-	1.6 ± 1.2	-	-
Protein	9.2	5.2		7.0	-	-	8.0 ± 5.0	-	11.0
Minerals	-	10.7	-	-	-	-	-	-	-

**TABLE 9** Procyanidins and flavanols in coffee by-products in Arabica and Robusta from Mexico, India, and China

Procyanidin and flavonoids	Mexico		India		China	
	Arabica	Robusta	Arabica	Robusta	Arabica	Robusta
Quercetin-O-rutinoside	23.1 ± 9.9	8.1 ± 0.9	3.9 ± 2.2	6.4 ± 3.5	2 ± 0.5	0.7 ± 0.2
Quercetin-3-O-rutinoside	153.8 ± 62.4	3.7 ± 0.2	1 ± 9.2	4.7 ± 2.5	9.8 ± 2.2	2.6 ± 0.5
Quercetin-3-O-galactoside	1.4 ± 0.7	2.9 ± 0.3	0.8 ± 0.3	2.9 ± 1.7	0.2 ± 0	0.1 ± 0
(+)-catechin	32.4 ± 7.8	n.d.	37.3 ± 15.6	7.7 ± 1.3	21.1 ± 6.2	0.1 ± 0.1
(-)-epicatechin	17.9 ± 2.6	n.d.	4.6 ± 2.1	n.d.	16 ± 2.5	0.5 ± 0.5

Abbreviation: n.d., nondetected.

**TABLE 10** Phenolic compound of tea waste

Compounds	Phenolic content (mg/g DW) <sup>a</sup>	
	Oven waste	Grade waste
Catechins		
Epicatechin	n.d.	n.d.
Epigallocatechin	n.d.	n.d.
Catechin	n.d.	n.d.
Gallocatechin	4.6	3.9 ± 0.21b
Epigallocatechingallate	1.0	0.9 ± 0.08b
Gallocatechingallate	n.d.	n.d.
Epicatechingallate	0.2	0.31 ± 0.02a
Total catechins	6.01	5.21 ± 0.28b
Total theaflavins	16.0 ± 0.59b	11.5 ± 0.50c
Gallic acid	0.6	0.5 ± 0.03b
Caffeine	16.5 ± 0.50b	16.0 ± 1.29b

Abbreviation: n.d., nondetected.

from China. The Arabica coffee husk from Mexico has the highest amount of flavanols. The difference in the chemical components could be due to the bean green process and roasting degree (Mullen, Nemzer, Stalmach, Ali, & Combet, 2013).

A number of studies have tried to use the coffee by-product in different aspects for new products. Some researchers endeavored to produce bioethanol from the coffee by-product. A combination of enzymatic treatment, heating, and steam was used. The results showed that ethanol efficiency of 83% per amount of glucose and yield bioethanol ranged from 0.426 ± 0.0015 g/L (Arrizon et al., 2012). Another study used high pressure and sulfuric acid to hydrolyze dried coffee by-products. The results showed that ethanol yield of 82 g/kg dry coffee pulp and the amount of ethanol produced was 0.45 g/g sugar (Shenoy et al., 2011). Gouvea et al. (2009) optimized best condition for ethanol production; it was found that using *Saccharomyces Cerevisiae* in sticky coffee husk fermentation resulted in best yield condition with the optimal temperature at 30°C and 3 g yeast/L. The yielded bioethanol was 8.49 ± 0.29 g/100 g dry husk (13.57 ± 0.45 g ethanol/L).

For health benefits, coffee by-products can be useful due to its content of bioactive compounds. Various studies have confirmed

**TABLE 11** Amino acid composition of tea leaf waste

Amino acids	g/100 g protein
Alanine	4.80
Arginine	4.90
Aspartic acid	8.00
Cystine	1.4
Glutamic acid	9.8
Glycine	4.6
Histidine	2.5
Isoleucine	4.2
Leucine	7.4
Lysine	6.3
Methionine	1.4
Phenylalanine	4.3
Proline	4.2
Serine	4.3
Threonine	4.0
Tyrosine	3.3
Valine	5.0

the fact that coffee by-products could be useful for health purposes. In a study about the benefits of coffee by-products in relation to prebiotic, antimicrobial, and antioxidant characteristics, it has been concluded that coffee silver skin and coffee spent grounds can potentially be used as functional ingredients. Furthermore, both of them can be useful as a source of prebiotic compounds, but melanoidins should be removed. Coffee silver skin and coffee spent grounds could be utilized as natural preservatives if used in large amount. Moreover, coffee silver skin and coffee spent grounds can be an important component to improve human health because of its antioxidant activity (Jiménez-Zamora, 2015). In another study, the antimicrobial activity of biologically active in coffee waste was studied, and it was found that coffee by-products showed an inhibitory activity against *S. aureus* and *Escherichia coli*. A stronger inhibition was also observed against *Candida sp.* growth (*C. albicans*, *C. Krusei*, and *C. parapsilosis* [Sousa, Gabriel, Cerqueira, Manso, & Vinha, 2015]).



**TABLE 12** The chemical composition of tea waste

Tea leaves waste	*C	*N	*CA	*K	*Mg	*Na	**Fe	**Zn	**M	**Cu
Quantity	502.9	502.9	6.7	13.1	30.4	6.6	187.	14.5	763.0	12.9

<sup>a</sup>Abbreviations: \*(mg/g);\*\*(μg/g); C, carbon; CA, calcium; Cu, copper; Fe, iron; Mg, magnesium; Mn, manganese; N, nitrogen; NA, sodium; Zn, zinc.

**TABLE 13** The compounds of the by-products of cheese

Compounds	Concentration (g/L)
α-Lactoglobulin	1.5
B-Lactoglobulin 3–4	3–4
Bovine serum, albumin	0.3–0.6
IgG, IgA, IgM	0.6–0.9
Lactoperoxidase	0.06
Lactoferrin	0.5

### 3.4 | Tea

Tea is one of the most consumed drinks worldwide and possesses strong phenolic content (Vladić et al., 2016). One of the waste parts is stalk and stem which are rich in dietary fiber removed during tea processing. However, tea leave waste is the main by-products of tea leaf industry. Tea by-products are normally disposed of as compost, dumped into lands, and/or burned. But these are not a reasonable solution since they cause both environmental and economic problems (Hossain, Ko, & Yang, 2012).

It has been reported that the flavanols are the most important compound of tea polyphenols that predominantly include catechins, such as epicatechin, epicatechin gallate, epigallocatechin, epigallocatechin gallate, and catechin. Since the tea leftover could contain similar components but with different quantities, a study was done on phenolic content of the black tea waste sample, oven waste, and grade waste. The results showed that both contain similar amount of polyphenolic compounds (Table 10). It was expected that the waste material contained less bioactive compound comparing to the free tea (Güçlü Üstündağ et al., 2016). The study concluded that tea waste is an important source of antioxidant and antimicrobial activity that can be used for different purposes such as food, pharmaceutical, cosmetic, and agricultural sectors. It was also stated that aqueous ethanol solvents could be the cheapest, nontoxic green alternative for antioxidant and antimicrobial phenolics from tea waste.

Alongside with the phenolic compound, it has also been reported that there are a number of amino acids in the tea leaf. Glutamic acid is the highest with 9.8 g/100 g protein, and cysteine and methionine are the lowest with 1.4 g/100 g protein (Table 11).

Regarding micronutrients, it has been found that tea by-products contain a number of elements as mentioned in Table 12 (Morikawa & Saigusa, 2008).

**TABLE 14** Bioactive peptides hydrolyzed from the casein and whey (modified from Muro Urista, Álvarez Fernández, Riera Rodríguez, Arana Cuenca, & Téllez Jurado, 2011)

Peptides	Microorganisms/enzymes
b-Lg, a-La	Trypsin
Na-Casein, b-casein, B-lactoglobulin, a-lactoalbumin	Pepsin, trypsin, K-proteinase, thermolysin LYQQP
as2-Casein	Lactobacillus different
k-Casein	Lactobacillus delbrueckii bulgaricus IFO13953
b-lactoglobulin	Lactobacillus rhamnosus, pepsin, and corolase PP
b-Casein	Lactobacillus bulgaricus
b-Casein	Streptococcus thermophilus + Lactococcus lactis biovar diacetylactis
b-Casein	Proteinase from <i>Enterococcus faecalis</i>
a-Casein	Trypsin
b-Lg	Thermolysin
b-Casein	Pepsin
Na-casein	Alcalase
Na-casein	Na-casein enzyme culture of bacterium and plants
Na-casein	Alcalase
Whey proteins	Alcalase
b-Lg	N-proteinase

### 3.5 | Dairy products

Dairy industry sector is the main and essential fraction of global food industry with having a magnificent quantity of watery waste. The most predominant waste that gained industrial attention is whey since it contains valuable bioactive nutrients.

Whey is one of the main by-products of the cheese manufacture process which is about the watery by-product left after the process. These by-products contain many bioactive proteins such as β-lactoglobulin, α-lactalbumin, bovine serum albumin, and immunoglobulins (Galali & Hane, 2019). It can be seen that the first two is particularly present in high concentration (Table 13). These perform important health functions. Therefore, this makes the whey valuable nutritionally (Asghar, Anjum, & Allen, 2011).

One of the main compounds of the milk by-products and whey is bioactive peptides. They have been labeled as protein fraction which imparts positive influence on body well-being through improving

**TABLE 15** Total phytosterol contents (as mg free sterols/g lipids) in total lipid extracts of cereal by-products

	Brassicasterol	Campesterol	Compestanol	Stigmasterol	Sitosterol	Sitostanol	Unknown 1	Unknown 2	Cycloartenol & like phytosterols	24-Methylenecycloartenol- & like phytosterols	Total mg/m lipids	Total mg/g Raw material
Rice bran	–	2.6	0.3	1.8	4.9	0.8	0.8	0.3	3.33 <sup>b</sup>	5.25 <sup>c</sup>	20.3	4.5
Wheat bran	0.5	3.6	1.7	0.2	4.5	2.4	0.6	0.3	0.48 <sup>d</sup>	3.01 <sup>d</sup>	17.6	1.2
Wheat germ	0.1	4.7	0.6	0.2	11.2	0.8	1.4	0.3	0.69 <sup>d</sup>	1.03 <sup>e</sup>	21.2	2.4
Durum wheat	0.5	2.1	2.9	0.3	4.7	2.1	1.1	0.1	0.31 <sup>d</sup>	0.70 <sup>e</sup>	15.0	1.8
Oat bran	–	0.2	0.04	0.1	1.5	0.07	0.6	0.0	0.26 <sup>b</sup>	0.38 <sup>c</sup>	3.4	1.5
Oat hull	–	0.6	0.09	0.5	4.0	0.4	0.7	0.20	0.53 <sup>b</sup>	0.85 <sup>c</sup>	8.1	0.7
Corn fine fiber	–	4.8	1.1	5.0	27.6	4.1	1.7	1.4	1.44 <sup>d</sup>	0.82 <sup>e</sup>	0.1	0.3

<sup>a</sup>This unknown peak was identified as lanosterol in rice bran lipids and as avenasterol in wheat bran and oat bran lipids. It was not identified in other samples.

<sup>b</sup>Identified as cycloartenol.

<sup>c</sup>Identified as 24-methylenecycloartenol.

<sup>d</sup>Unidentified compounds that had the same GC retention time as cycloartenol but had different MS spectra.

<sup>e</sup>Unidentified compounds that had the same GC retention time as 24-methylenecycloartenol but had different MS spectra.

A dash (–) indicates not detected.

**TABLE 16** Dietary fiber content of some cereal by-products (% on dry matter basis)

By-product	Fiber quantity (g)
Rice bran	27.0
Wheat bran	44.4
Corn bran	87.8
Sesame coat	42.0
Oat bran	23.8

body functions. Recently, milk whey has gained attraction by the technicians and scientists to be used as a source of bioactive peptides for industrial purpose (Table 14). They can possess physiological benefits and contribute to the pharmaceutical and functional food formulation.

### 3.6 | Cereal products

It has been reported that the rice bran has the highest content of phytosterols by 4.5 mg/g bran. Furthermore, wheat germ and durum wheat, oat bran, and wheat bran had 2.4, 1.8, 1.5, and 1.5 mg/g content of phytosterols, respectively, (Table 15; Jiang & Wang, 2005), whereas the lowest phytosterol found in oat hull was 0.7 mg/g. In another study, it has been found that oil yields (g kg<sup>-1</sup> dry weight) extracted from cereal waste products were as follows: 189 for rice bran, 112 for wheat germ, 74 for corn bran, 58 for oat bran, 41 for buckwheat bran, 39 for spelt bran, 33 for wheat bran, and 27 for rye bran. Furthermore, the major fatty acids determined in the samples were palmitic acid by 11.39%–17.23%, oleic acid by 11.76%–42.73%, linoleic acid by 35.54%–62.65%, and  $\alpha$ -linolenic acid by 1.05%–9.46%. Moreover, the total tocopherols and phytosterols were quantified in the oils (0.369–3.763 and 1.19–35.24 g kg<sup>-1</sup> of oil, respectively). The extracted oils from buckwheat and corn bran, and wheat germ were dominated by tocopherols (99.9%, 84.2%, and 96.5%, respectively), while the oat, rice, rye, spelt, and wheat bran oils seem to be rich in tocotrienols (73.9%, 79.6%, 78.1%, 90.6%, and 73.8%), respectively (Górnaś, Rudzińska, Raczky, & Soliven, 2016).

Another by-product component in the cereal by-product is dietary fibers in different quantities. Corn bran seems to be richest by-product by 87.86 g followed by wheat bran 44.46 g and sesame coat by 42 g, whereas the lowest fiber content is in oat bran by 23.8 g (Table 16; Elleuch et al., 2011). These dietary fibers have been used in many products including breads (Al-Dmoor & Galali, 2014; Galali, 2014).

### 3.7 | Nuts

Nut by-products could include skin or testa, hard shell, green leafy cover, hull, and leaf. These are important and valuable sources of bioactive compounds that have multifunctional traits and antioxidant activity, and antimutagenic, anticarcinogenic, and antiproliferative

TABLE 17 Bioactive compounds in nuts almond

Nuts	Bioactive compounds	Skin	Hard shell	Hull/pellet
Almond	Flavonols (g/g)	4.19–4.87 <sup>a</sup> , 10.9 <sup>b</sup>	nr	
	Isorhamnetin	8.9–15.6 <sup>a</sup> , 139 <sup>b</sup> 27.6–41.4 <sup>a</sup> ,		
	Isorhamnetin-3-O-glucoside	639 <sup>b</sup> 1.71–1.96 <sup>a</sup> , 2.4 <sup>b</sup> 49.9 <sup>b</sup>		
	Isorhamnetin-3-O-rutinoside	1.65 <sup>a</sup> , 23.2 <sup>b</sup>		
	Kaempferol	12.8–31.8 <sup>a</sup> , 196 <sup>b</sup>		
	Dihydroxykaempferol	0–10.3 <sup>a</sup>		
	Kaempferol-3-O-glucoside	1.43–1.78 <sup>a</sup> , 3.12 <sup>b</sup>		
	Kaempferol-3-O-rutinoside	1.33–2.41 <sup>a</sup>		
	Dihydroquercetin	6.45 <sup>b</sup>		
	Quercetin	8.15 <sup>b</sup>		
	Quercetin-3-O-glucoside	20.1–38.3		
	Quercetin-3-O-galactoside	7.2–26.5		
	Quercetin-3-O-rutinoside	0.15		
	Flavan-3-ols (mg/100g) fresh weight	2.4–3.5		
	(+)-Catechin	1.2–4.8		
	(-)-Epicatechin	3.2–4.9		
	(-)-Epicatechin-3-gallate	2.5–4.9		
	Unknown dimer A [(epi)catechin→	83.4 <sup>a</sup>		
	A→(epi)catechin]	6.84–22.1 <sup>c</sup>		
	Unknown dimer A	2.75 <sup>a</sup>		
	[(epi)catechin→A→(epi)catechin]	0.8–1.6 <sup>c</sup>		
	Unknown dimer A	11.8–23.8 <sup>c</sup>		
	[(epi)catechin→A→(epi)catechin]	5.34–16.1 <sup>c</sup>		
	Unknown dimer A [(epi)catechin→	nd <sup>c</sup>		
	A→(epi)catechin]	5.63–13.9 <sup>c</sup>		
	Flavanone (g/g)	3.5–8.6 <sup>c</sup>		
	Naringenin	3.45–15.3 <sup>c</sup>		
	Naringenin-7-O-glucoside	3.2–7.0 <sup>c</sup>		
	Eriodictyol	1.4–6.3 <sup>c</sup>		
	Eriodictyol-7-O-glucoside	4.0–7.3 <sup>c</sup>		
	Anthocyanidins	0.7–2.04 <sup>c</sup>		
	Procyanidin B3 + B1	0.9–1.8 <sup>c</sup>		
	Procyanidin B2	1.6–4.3 <sup>c</sup>		
	Procyanidin B3			
	Procyanidin B7			
	Procyanidin B5			
Procyanidin C1				
A-type procyanidin dimer				
A-type procyanidin dimer				
A-type procyanidin dimer				
A-type procyanidin dimer				
A-type prodelfphinidin dimer				
A-type procyanidin trimer				
Brazil nut (g/g) defatted	Flavan-3-ols	2875 <sup>d</sup>		
	Catechin	1316 <sup>d</sup>		
	Gallocatechin	28.2 <sup>d</sup>		
	Flavonols	333 <sup>d</sup> , 123 <sup>e</sup>		
	Quercetin			
	Flavanonol			
	Taxifolin			

(Continues)

TABLE 17 (Continued)

Nuts	Bioactive compounds	Skin	Hard shell	Hull/pellet
Hazelnut	Flavan-3-ols	nr	0.3–0.8 <sup>f</sup>	20.13 <sup>g,h</sup>
	Catechin			9.26 <sup>g</sup>
	Epicatechin			1.37 <sup>g</sup>
	Epicatechin-3-gallate			99.2 <sup>g</sup>
	Procyanidin dimer 1			19.2 <sup>g</sup>
	Procyanidin dimer 2			0.4 <sup>g</sup>
	Procyanidin dimer 3			7.0 <sup>g</sup>
	Procyanidin trimer 1			2.47 <sup>g</sup>
	Procyanidin trimer 2			14.7 <sup>g</sup>
	Procyanidin trimer 3			8.4 <sup>g</sup>
	Procyanidin trimer 4			3.7 <sup>g</sup>
	Procyanidin trimer 5			
	Flavonoids <sup>c</sup>	0.2 <sup>f</sup>		3.61 <sup>g</sup>
	Procyanidin trimer 6	0.2–1.0 <sup>f</sup>		2.37 <sup>g</sup>
	Procyanidin tetramer 1			2.3 <sup>g</sup>
	Procyanidin tetramer 2			6.83 <sup>g</sup>
Procyanidin tetramer 3			nr <sup>g</sup>	
Procyanidin B2			17.7 <sup>g</sup>	
Flavonols			nr	
Myricetin-3-O-rhamnoside			50.14 <sup>g</sup>	
Quercetin-pentoside			nr	
Quercetin-3-O-rhamnoside			0.97 <sup>g</sup>	
Quercetin-3-O-rutinoside			39.26 <sup>g</sup>	
Hydrolyzable tannins			71.71 <sup>g</sup>	
B type dimer gallate			6.53 <sup>g</sup>	
Glansreginin A			18.7 <sup>g</sup>	
Glansreginin B				
Dihydrochalcones				
Phloretin-2-O-glucoside				
Pecan	Flavan-3-ols mg/g dry weight		nr	
	Catechin		102 <sup>i</sup> , 0.3 <sup>j</sup>	
	Epicatechin		120 <sup>k</sup> , 1326 <sup>l</sup>	
	Epigallocatechin g/ml		0.3 <sup>k</sup> , 0.9	
	Epicatechin gallate			
Peanuts	p-Coumaroyl-O-pentosid (mg/100g dw)	5.5	0.9	
	Flavonols	1.5	2.4	
	Isorhamnetin	2.1	0.5	
	Quercetin	0.4		
	Flavone	0.3		
	Diosmetin	6.2		
	Stilbenes	0.7		
	trans-Resveratrol	21.1		
	Proanthocyanidins	19.5		
	Proanthocyanidin A-type dimers	8.3		
	Proanthocyanidin B-type dimers	15.4		
	Proanthocyanidin trimers	13.6		
	Proanthocyanidin tetramers	6.9		
	Proanthocyanidin hexamers			
	Proanthocyanidin heptamers			
	Proanthocyanidin octamers			
	Flavanone (mg/g) dry weight			
	Eriodictyol			
	Flavone			
	Luteolin			
5,7-Dihydroxychromone				

(Continues)

TABLE 17 (Continued)

Nuts	Bioactive compounds	Skin	Hard shell	Hull/pellet
Pistachio	Flavan-3-ols g/g extract	377, 140	nr-1240	
	Catechin	105, 27.5	630-980	
	Epicatechin	nr, 55	nr	
	Flavanols	nr	95-120	
	Procyanidin dimer	366	nr	
	Flavanone	0.21-3.35	nr	
	Hesperidin	63.2, 14	nr	
	Eriodictyol-7-O-glucoside	11.4, 2	nr	
	Eriodictyol-3-O-hexoside	119	nr	
	Eriodictyol	nr <sup>m</sup>	145-190	
	Naringenin	nr, 30	nr	
	Naringenin-7-O-neohesperidoside	17.8 <sup>m</sup> , 13.7 <sup>n</sup>	255-620	
	Flavone	5.1	nr	
	Apigenin	49	nr	
	Luteolin	2.68	nr	
	Flavonols	0.9	nr	
	Quercetin	1.6		
	Quercetin-3-O-rutinoside	Nr		
	Quercetin-3-O-glucoside	nr		
	Quercetin-3-O-hexoside	nr		
	Kaempferol	5865 <sup>m</sup> , 21.1 <sup>n</sup>		
	Myricetin	32.6 <sup>m</sup> , 0.6 <sup>o</sup>		
	Isoflavones			
	Daidzein			
	Genistein			
	Genistein-7-O-glucoside			
	Anthocyanins			
	Cyanidin-3-O-galactoside			
Cyanidin-3-O-glucoside				
Walnut	Flavan-3-ols mg/kg fw			26.9 <sup>P</sup>
	Catechin			157 <sup>P</sup>
	Procyanidin dimer 1			1.2 <sup>P</sup>
	Procyanidin dimer 2			1.8 <sup>P</sup>
	Procyanidin trimer			281 <sup>P</sup>
	Procyanidin tetramer			95.5 <sup>P</sup>
	Hydrolysable tannins			50.9 <sup>P</sup>
	Galloyl bis HHDP glucose 1			22 <sup>P</sup>
	Galloyl bis HHDP glucose 2			597 <sup>P</sup>
	Glansreginin B			35.5 <sup>P</sup>
	Glansreginin A			47.5 <sup>P</sup>
	HHDP digalloyl glucose isomer 1			14.53 <sup>P</sup>
	HHDP digalloyl glucose isomer 2			22 <sup>P</sup>
	HHDP digalloyl glucose isomer 3			57.5 <sup>P</sup>
	HHDP galloyl glucose 1			21.3 <sup>P</sup>
	HHDP galloyl glucose 2			115 <sup>P</sup>
	Di-galloylglucose			133 <sup>P</sup>
	Di-HHDP glucose isomer 1			43.4 <sup>P</sup>
	Di-HHDP glucose isomer 2			27.8
	Di-HHDP glucose isomer 3			32.4 <sup>P</sup>
	Di-HHDP glucose isomer 4			49.4 <sup>P</sup>
	Vescalagin isomer 1			22.7
	Vescalagin isomer 2			100 <sup>P</sup>
	Vescalagin isomer 3			35.3 <sup>P</sup>
	Vescalagin isomer 4			17.1 <sup>P</sup>
	Vescalagin isomer 5			4.89 <sup>P</sup>
Vescalagin isomer 6			1.4 <sup>P</sup>	

(Continues)

TABLE 17 (Continued)

Nuts	Bioactive compounds	Skin	Hard shell	Hull/pellet
Walnut	Q-galloyl pentoside 1			4.8 <sup>P</sup>
	Q-galloyl pentoside 2			16 <sup>P</sup>
	Q-galloyl pentoside			2.9 <sup>P</sup>
	Unknown 429			
	Unknown 459			

Abbreviation: Nr, none detected.

<sup>a</sup>Data are expressed as g/g skin.

<sup>b</sup>Data are expressed as g/g skin.

<sup>c</sup>Range (minimum – maximum) values (expressed in g/100 g dw) obtained from eight varieties.

<sup>d</sup>Bound phenolics.

<sup>e</sup>Free phenolics.

<sup>f</sup>Range (minimum – maximum) values (free phenolics expressed as g/g dw of kernel or hard shell).

<sup>g</sup>Values (mg/kg).

<sup>h</sup>Values obtained from dry-blanching.

<sup>i</sup>Shell extract.

<sup>j</sup>Extract of whole shell.

<sup>k</sup>Ethanol extract.

<sup>l</sup>Extract treated with infusion and spray dryer.

<sup>m</sup>Bound phenolic acids.

<sup>n</sup>Mean content obtained from six Argentinian varieties.

<sup>o</sup>Values (expressed in g/g dw).

<sup>p</sup>Values (expressed in g/g fw).

TABLE 18 Amino acid composition of decalcified eggshell and eggshell membranes (Mol%)

Amino acids	Decalcified eggshell	Inner shell membrane	Outer shell membrane
Asx	8.1	8.4	8.8
Thr	6.2	6.9	6.9
Ser	9.7	9.2	9.2
Glx	11.8	11.1	11.9
Gly	13.0	11.1	10.6
Ala	6.9	4.6	4.1
Val	7.3	7.2	7.9
Met	2.0	2.3	2.3
Ile	2.6	3.3	3.4
Leu	6.1	5.6	4.8
Tyr	1.8	2.2	1.7
Phe	2.1	1.6	1.5
His	4.2	4.1	4.3
Lys	3.6	3.6	3.4
Arg	5.9	5.7	5.8
Pro	8.3	11.6	12.0
Hyp1	0.3	1.5	1.4

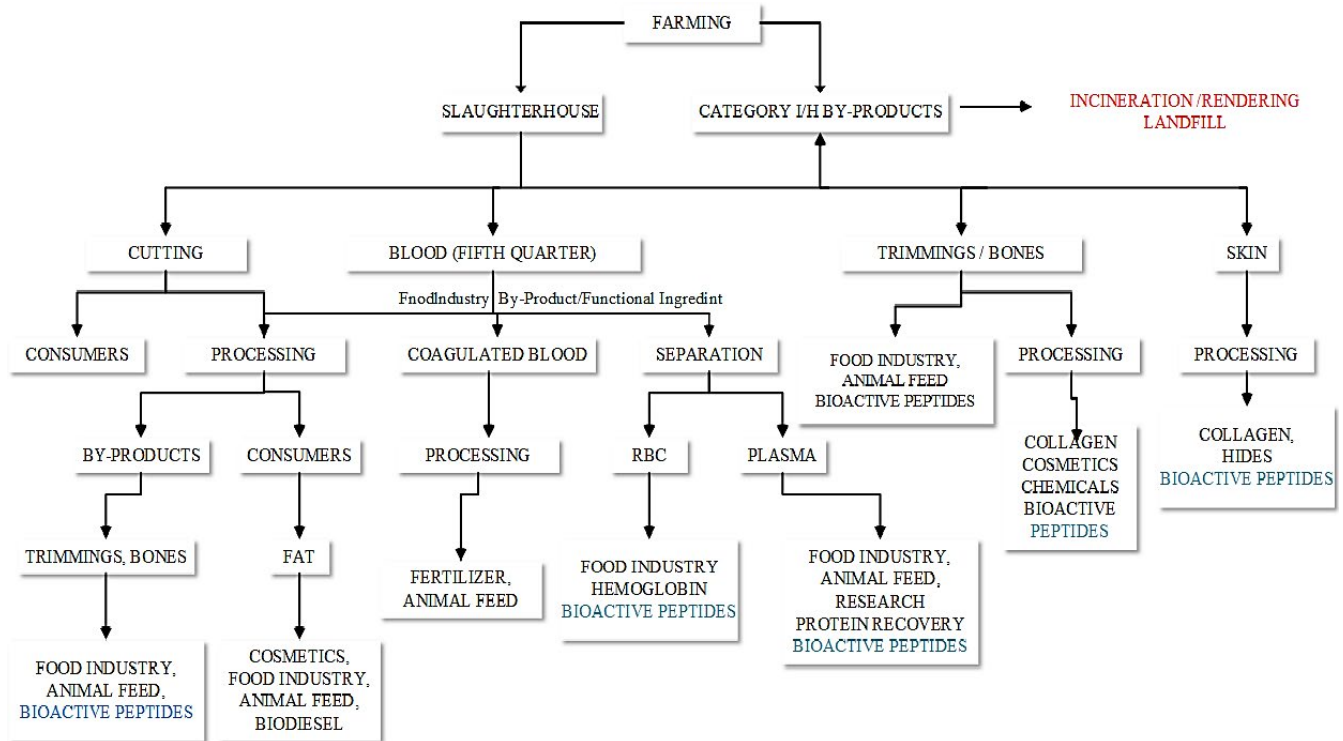
Abbreviations: Ala, alanine; Arg, arginine; Asx, asparagine; Glx, glutamate; Gly, glycine; His, histidine; Hyp, hydroxyproline; Ile, isoleucine; Leu, leucine; Lys, lysine; Met, methionine; Phe, phenylalanine; Pro, proline; Ser, serine; Thr, threonine; Tyr, tyrosine; Val, valine.

TABLE 19 Amino acid composition of egg by-products (wastewater) (g amino acid/100 g total protein)

Amino acids	Electrocoagulation
Threonine	4.1
Valine	6.1
Cystine <sup>a</sup>	–
Methionine <sup>a</sup>	–
Isoleucine	5.6
Leucine	8.4
Phenylalanine	5.1
Tryptophan <sup>a</sup>	–
Lysine	6.4

<sup>a</sup>Destroyed by acid hydrolysis.

properties (Shahidi & Ambigaipalan, 2015). The bioactive compounds of these components involve in the protection of the body directly or indirectly through detrimental free radicals and diminish the risks of the diet-associated diseases. Thus, inclusion of these compounds in the daily meal is highly recommended by health expertise which can protect the body from harmful compounds (Alasalvar & Bolling, 2015). Regarding the nut coproducts, there are different biologically active compounds that have been determined and reported. Flavonoids including catechin, epicatechin, eriodictyol-7-O-glucoside, quercetin-3-O-rutinoside, quercetin-3-O-galactoside, quercetin-3-O-glucoside, kaempferol-3-O-rutinoside, naringenin-7-O-glucoside, isorhamnetin-3-O-rutinoside, kaemp-



**FIGURE 1** Major utilizes of meat muscle and by-products

ferol-3-O-glucoside, isorhamnetin-3-O-glucoside, eriodictyol, quercetin, naringenin, kaempferol, and isorhamnetin are commonly found in the coproducts of almond, hazelnut, and pistachio. Recently, procyanidin dimers, trimers, and tetramers as well as dihydrochalcones such as phloretin-2-O-glucoside have been reported only in hazelnut pellet. Isoflavones, such as daidzein and genistein, have not been found in pistachio coproducts compared with raw pistachio. Flavones, such as luteolin and 5, 7-dihydroxychromone, were only found in peanut shell. In addition, apigenin is only determined in pistachio hard shell, while diosmetin is found only in peanut skin (Table 17). So far, no studies have been reported about the flavonoid contents of the shell and hull/ pellet of almond, peanut, and Brazil nut. In this connection, the flavonoids of cashew coproducts have not been reported here (Chang, Alasalvar, Bolling, & Shahidi, 2016).

### 3.8 | Egg

Egg by-products mainly include eggshells and membranes (King'ori, 2017), wastewater from egg processing industry (Xu, Sheldon, Larick, & Carawan, 2002), and outcomes from breaking facilities and unsellable eggs (El-Deek, Al-Harathi, & Attia, 2011). Eggshells are waste products that are generated by different sources such as home, hatcheries, and fast food industry and which causes environmental pollution. The disposal challenges include eggshells include cost, availability of disposal places, smell, flies, and abrasiveness. However, they can be utilized for plants, human, and animal nutrition and produce collagen (Amu, Fajobi, & Oke, 2005).

Eggshell has been reported possessing many important nutrients such a calcium and trace amounts of other micro-elements, that is, magnesium, boron, copper, iron, manganese, molybdenum, sulfur, silicon, and zinc (King'ori, 2017). A medium-sized complete eggshell could give 750–800 mg of calcium. The calcium with magnesium and vitamin D increases mineral bone density (Schaafsma et al., 2018). Eggshells are also used as a cheap source of calcium in fertilizing plants (Amu et al., 2005). Shell membrane is an important by-product source for collagen which can be used medicinally and industrially (Ogawa, Portier, Moody, & Bell, 2004). Also, eggshell and membrane contain many biologically active peptides (Table 18; Nakano, Ikawa, & Ozimek, 2003).

Wastewater from egg industry is another by-product of egg that contains many biologically active peptides. It can be seen that there are a number of peptides in the wastewater which some of them are destroyed with acid hydrolysis (Table 19; Xu et al., 2002).

Protein peptides are also other bioactive compounds that are produced from egg processing by-products. In a study about the egg-yolk protein by-product as a source of biologically active compounds, the following peptides sequences are produced: RASDPLLSV, RNDDLNYIQ, LAPSLPGKPKPD, and AGTCLFTPLALPYDYSH. Peptides have pharmaceutical, medicinal, and functional properties in foods (Eckert, Zambrowicz, Pokora, & Setner, 2014).

### 3.9 | Meat

Meat like any other food products has a number of waste parts, but it is dissimilar depending on traditions, culture, and religion.

**TABLE 20** Bioactive peptides in meat and meat by-products with some modification

Bioactivity	Source	Parental protein
PEP-inhibitory	Bovine brain	38–55 glial fibrillary acidic
Opioid	Bovine blood	Hemoglobin
Opioid	Bovine blood	Hemoglobin
Antithrombotic	Porcine muscle	-
Antithrombotic	Porcine muscle	-
Antioxidant	Porcine muscle	Integrin $\alpha$ -3
Antioxidant	Porcine muscle	Collagen $\alpha$ -1 (VII)
Antioxidant	Venison muscle	-
Antioxidant	Venison muscle	-
Antioxidant	Porcine muscle	Actin
Antioxidant	Porcine muscle	-
Antioxidant	Porcine muscle	Tropomyosin
Antioxidant	Porcine muscle	Tropomyosin
Antioxidant	Porcine muscle	Myosin heavy chain
Antioxidant	Porcine muscle	-
Antioxidant	Buffalo horn	-
Antioxidant	Buffalo horn	-
Antioxidant	Buffalo horn	-
Antioxidant	Bovine muscle	1–12 myoglobin
Antioxidant	Bovine muscle	1–13 myoglobin
Antioxidant	Porcine blood	Hemoglobin
Antioxidant	Skin	Collagen
Antioxidant	Porcine blood	Plasma globulin/albumin
Antioxidant	Porcine blood	Plasma proteins
Antioxidant	Porcine blood	Plasma proteins
Antimicrobial	Bovine blood	33–61 $\alpha$ -hemoglobin
Antimicrobial	Bovine blood	1–23 $\alpha$ -hemoglobin
Antimicrobial	Bovine blood	107–136 $\alpha$ -hemoglobin
Antimicrobial	Bovine blood	107–141 $\alpha$ -hemoglobin
Antimicrobial	Bovine blood	137–141 $\alpha$ -hemoglobin
Antimicrobial	Bovine blood	133–141 $\alpha$ -hemoglobin
Antimicrobial	Bovine blood	126–145 $\beta$ -hemoglobin
Antimicrobial	Bovine blood	$\alpha$ -Hemoglobin
Antimicrobial	Beef muscle	-
Antimicrobial	Bovine blood	Hemoglobin
PEP-inhibitory	Bovine brain	38–55 glial fibrillary acidic
Opioid	Bovine blood	Hemoglobin
Opioid	Bovine blood	Hemoglobin
Antithrombotic	Porcine muscle	-

However, general meat processing by-products include skin, bones, meat trimmings, blood, fatty tissues, horns, feet, hoofs, or internal organs (Toldrá, Aristoy, Mora, & Reig, 2012). Meat by-products are rich in many nutrients such as carbohydrate, protein, and fat that have different applications (Figure 1). Furthermore, collagen is one of the most abundant bioactive compounds of skin, bone, and horn

(Gómez-Guillén, Giménez, & López-Caballero, 2011). Despite having medicinal and industrial usage, collagen is a precursor for many bioactive peptides with the sequences of antihypertensive, antithrombotic, and dipeptidyl peptidase-IV (DPP-IV, EC 3.4.14.5; Minkiewicz, Dziuba, & Michalska, 2011).

Blood is another by-product of meat which is rich in protein such as fibrinogen, globulins, and albumins and hemoglobin (Bah, Bekhit, Carne, & Mcconnell, 2013). Blood and other by-products are sources of bioactive peptides with different biological activities (Table 20; Lafarga & Hayes, 2014).

Animal horn is another waste product with many nutrients that can act and possess biologically active compound. In a study about elemental analysis of animal horn, there were a number of important elements including P, K, Ca, Mn, Fe, and Zn. The study also analyzed elemental composition of bone. It was found that there are same elements as horn plus Cr, Cd, Sn, and Ag (Buddhachat, Klinhom, & Siengdee, 2016).

## 4 | CONCLUSIONS

To summarize, food processing by-products accumulate in tons and cause huge environmental and economic problems in different stage and food industry sectors including fruits, vegetables, cereals, meat, dairy products, eggs coffee, and tea. If this would be studied and exploited carefully, they can be recycled and re-used in different areas such as food industry, pharmaceuticals, and other biotechnical areas. These food by-products are still containing many important biologically active compounds including fatty acids, amino acids, vitamins, minerals, dietary fibers, and antioxidants which can be useful economically and pharmaceutically (e.g., antimicrobials) in different aforementioned sectors instead of throwing into the ground. It is worth mentioning that different novel techniques have been examined in order to increase the potent of recovery of bioactive compounds from food by-products. They are superior to conventional methods. This attributes the fact that they are eco-friendlier, less hazardous, and less expensive. Therefore, it is important to choose a method that suits the intended bioactive compound to be extracted from different parts of the by-product.

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## CONFLICT OF INTEREST

The authors declare that they do not have any conflict of interest.

## ETHICAL APPROVAL

This study does not involve any human or animal testing.

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