Fruit by-Products

Subjects: Nutrition & Dietetics
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Fruit by-Products deals with the bioactive compounds present in the by-products generated by the fruit processing industry with large amounts. These bioactive compounds are mainly dietary fibres, phenolic compounds, proteins and lipids. They have significant chemical, physical and biological properties which make fruits by-products a good source for new supplements in food products having important effect on intestinal function.

Keywords: Fruit by-Products ; Bioactive compounds ; Dietary fibres ; Phenolic compounds ; Proteins ; Lipids ; Food

1. Introduction

The significant progress made in the field of chemistry, biology and agriculture has enabled better exploitation of agro-resources. Food is not seen as a simple nourishment, but its beneficial or harmful effects for the organism, and its role in the prevention of cardiovascular and metabolic pathologies are taken into consideration. No less important for the consumer is the impact on the environment of food production, both in terms of energy and human resources used, and of residues generated by agronomic practices, transformation and conservation. In this context the recovery of waste from agro-resource processing industries is considered of notable importance not only for economic matters but also for environmental sustainability, and offers new opportunities for economic development in many sectors. Thus, the economic burden of recycling waste becomes the production of high value-added co-products intended for resale to the biomedical, food, cosmetics, chemistry and design packaging materials industries [1][2]. The use of agro-resources and their co-products is motivated by their abundance, their renewable nature, their biodegradability and the added value which must justify any industrial development. Indeed, agro-resources could offer a new source of raw materials in many fields.

Even if the current globalization of the market ensures the availability of fresh fruit throughout the year, a large part is subjected to different transformation processes in order to obtain new products satisfying the different current demands of consumers. Thus, it has been reported that about a third of the edible portion of food intended for human consumption is lost or wasted along the food chain, from initial production to final consumption [3][4]. The large quantity of residues produced by the food industry, in addition to being a great loss of valuable materials, also raises serious management problems from an economic and ecological point of view. To address these economic and ecological problems, the recovery of residues represents a promising solution to absorb millions of tons of waste material. The valorization of by-products from the food industry gives a second life to co-products and limits the use of conventional energy sources [5].

2. Bioactive Compounds from Fruit by-Products

Several researches have proven the presence of a wide range of bioactive compounds in various fruit industrial by-products which are essentially pomace, peels and seed fractions. These compounds consist mainly of carbohydrates (pectin, cellulose, hemicellulose…), secondary metabolites (phenolics, glycosides, alkaloids, gums, mucilage and volatile oils), lipids and proteins. Generally, seeds are rich in polyphenols and bioactive lipids whereas peels are considered as a rich source of dietary fibres [10][11]. Bioactive compounds are present in fruit by-products with various concentrations and combinations. These differences could be mainly related to the fruit variety, geographic location, maturation stage, as well as extraction parameters (solvent, extraction ratio, time and temperature) [9].

Several extraction techniques were carried out for the isolation of bioactive compounds from fruit by-products. For example, solid state fermentation (SSF) was applied for the extraction of polyphenolic antioxidants from grape skin [12] and bagasse [13] and for the isolation of ellagic acid from pomegranate Husks [14]. Citric acid was isolated from banana peel by SSF using *Aspergillus niger* [15], while pectin and limonene were extracted from orange peel through enzymatic and chemical hydrolysis [16]. Mango peels were subjected to autoclave treatment for the extraction of pectin and polyphenols [17]. The other processes that we can cite are ultrasound treatment (fatty acids and tocopherols from watermelon seeds) [18], microwave-assisted extraction (phenolic compounds from pitaya fruit peels) [19], steam explosion (limonene from orange peel) [20] and classic extraction with ethanol (phenolic antioxidants from avocado peel) [21] or nhexane (antioxidant oils from melon seeds and carotenoids and anthocyanins from papaya peel) [22][23]. Another modern method for the isolation of bioactive compounds from fruit by-products is sub- and supercritical fluid extractions. This method was applied for the extraction of phenolic compounds, flavonoids, carotenoids, pectin, reducing sugars, lipids and proteins from several by-products such as citrus peels and pomace, pomegranate peels, apple pomace and seeds, grape pomace and seeds [24].

Plant bioactive metabolites exert pleiotropic effects by the modulation of multiple metabolic pathways through a variety of molecular targets. Previous studies revealed that dietary phenolic compounds displayed a pleiotropic behavior on key proteins, thus presenting beneficial effects in several chronic disorders which are related to oxidative stress, inflammation and aging. This is strongly related to the wide range of biological activities like antioxidant, antimicrobial, anti-inflammatory, anti-allergenic, anticancer and cardioprotective activities. Thus, it has been reported that natural phenolic compounds and their metabolites exerted significant effects on the main metabolic pathways involved in energy metabolism (the AMP-protein kinase AMPK and the mammalian target of rapamycin mTOR are the main regulators), as well as inflammatory response and aging (main regulators are the nuclear factor-erythroid 2 p45-related factor 2 (Nrf2) and sirtuins) [25][26]. For example, Marín-Aguila et al. (2013) described some nutraceutical compounds targeting AMPK pathways in cancer, cardiovascular disease, type 2 diabetes mellitus and neurodegenerative disease including phenolic acids, anthocyanins, stilbene, flavone, flavonol, alkaloids, lignan [26]. Thus, bioactive compounds isolated from fruit by-products showed a significant effect as bioingredients in functional foods as well as nutraceuticals in pharmaceutical and medicinal recipes. This was mainly due to their antioxidant, anti-inflammatory, antimicrobial, anti-allergenic, antithrombotic, anti-atherogenic, cardioprotective and vasodilatory capacities [11].

2.1. Phenolic Compounds

Various phenolic compounds were isolated such as hydroxybenzoic and hydroxycinnamic acids, flavonoids (flavonols, flavanones, flavones, flavanonols, isoflavones, flavanols, and anthocyanidins), lignans and stilbenes (Table 1). Many fruit wastes showed highest phenolic content, especially grape, pomegranate, apple and citrus varieties (orange, lemon).

Indeed, the interest accorded to these compounds was mainly related to their capacity to scavenge free radicals and to regulate the generation of free radicals in vivo, thus ensuring the prevention of oxidation reactions in food and cell damage. These characteristics allows them to replace synthetic preservatives [10].

For example, an important oxidative stability was found in the oil extracted from date seeds due to the higher phenolic content (about 19 mg GAE/g dry weight). This ensures the use of date seed oil as natural additive to other vegetable oils in order to improve its heat stability [27][28]. In addition, big amounts of seeds and peels residues are generated by the citrus industry. These residues constitute about 50% of the total fruit and are an important source of phenolic compounds. Also, it has been reported that the peels of many fruits, such as apples, peaches, pears, banana and pomegranate, have been found to contain highest content in phenolics than the edible portions [29].

Table 1. Content of phenolic compounds in some fruit by-products.

Fruit by-Product	TPC	Phenolic Compounds	References
Pomegranate peel	139.4 * 420.6 ***	Punicalagin A, punicalagin B, catechin, gallic acid, ellagic acid	[30][31][32]
Pomegranate pomace	134.8 **	Gallic acid, catechin, ellagic acid, rosmarinic acid, hesperidin, p-coumaric acid, chlorogenic acid	[33][34]
Rowanberry pomace	167.4 ****	Cyanidin, Chlorogenic acid, quercetin, kaempferol	[35][36]
Apple pomace	13.8 *	Hydroxycinnamic acids, Hydroxycinnamates, phloretin glycosides, quercetin glycosides, catechins, procyanidins	[37][38]

Apple peel	34.3 *	Gallic acid, caffeic acid, vanillic acid, catechin, epicatechin gallate, chlorogenic acids, phloridzin, rutin	[38][39]
Banana peel	29.2 *	Epicatechin, rutin, hydroxybenzoic acid, myricetin, ferulic acid, chlorogenic acid, gallic acid	[40]
Date by-products	4.4 *	Quercetin, luteolin, apigenin, chrysoeriol, kaempferol, isorhamnetin, malonyl derivatives	[41][42]
Elderberry pomace	4.7 *	Cyanidin, rutin, oleanolic acid, ursolic acid, linoleic acid	[43][44]
Grape juice by-product	23.4 *	Benzoic and hydroxycinnamic derivatives, catechins, flavanols, anthocyanins, tannins, proanthocyanidins	[45][46]
Grape pomace	142.1 *	Phenolic acids (ferulic, p-coumaric, caffeic, gallic, vanillic, p-hydroxybenzoic), flavanols (proanthocyanidins), flavonols (kaempferol, quercetin, myricetin), stilbenes (resveratrol, piceid, astringin), anthocyanins	[47][48]
Grape seed	74.0 *	Gallic acid, caftaric acid, catechin, epicatechin, epicatechin gallate, procyanidins, resveratrol	[48][49][50]
Mango kernel	72.1 *	Gallates, gallotannins, gallic acid, ellagic acid and its derivatives	[48][51]
Orange by-product	4.21 *	Caffeic acid, Ferulic acid, p-Coumaric acid, Eriocitrin, Narirutin, Hesperidin, Neohesperidin	[52][53]
Orange peel	65.7 *	Caffeic acid, p-coumaric acid, naringin, kaempferol, neohesperidin, rutin	[54]
Orange pulp	22.3 *	Flavonone (Eriocitrin, Narirutin, Hesperidin, Didymin…), Flavone (Quercitrin, Nobiletin…), Kaemperol, Benzoic acids, Cinnamic acids, Chlorogenic acid,	[55]
Lemon peel	49.8 *	Caffeic acid, Coumaric acid, Ferulic acid, Sinapic acid	[56][57]
Passion fruit by-products	3.84 *	p-coumaric acid, Epicatechin	[52][58]
Guava by-product	19.9 *	Resveratrol, coumarin	[23]
Cherry by-product	91.3 *	Flavonoids, anthocyanidins, stilbenes, resveratrol, quercetin, gallic acid	[59]

* mg gallic acid eq./g extract DW; ** mg gallic acid eq./g liquid extract; *** mg tannic acid eq./g extract DW; **** mg catechin eq./g extract DW.

2.2. Dietary Fibres (DFs)

Over the last decades, there has been an increasing trend to recover dietary fibre (DF) compounds from industrial by-products. These compounds refer essentially to the sum of non-starch polysaccharides and lignin. Thus, it has been reported that fruit by-products are mainly composed of cellulose, hemicellulose, pectin, gums and lignin [10].

Table 2 illustrates some DF compounds isolated from various fruit by-products.

DF compounds can be obtained from the by-products of various food processing industry, such as the beverage, canning and juice industries. This latter probably produces the most important amounts of by-products, composed mainly by pomace and peels [60].

From a general aspect, the interest given to DF is strongly associated to their significant role in decreasing many health disorders. Cellulose, hemicellulose and lignin are well-known for water absorption and intestinal regulation, whereas pectin and gums showed important effects in cholesterol reducing and glucose regulation [61].

Table 2. Dietary fibre content in some fruit by-products.

Fruit by-Product	**TDF (g/100 DW)**	**References**
Apple Pomace	45.0	[62]
Apple Peel	43.9	[63]
Apple by product	75.8	[64]
Banana Peel	49.6	[40]
Orange Pomace	63.8	[65]
Orange Peel	48.7	[66]
Orange by-product	58.2	[52]
Passion fruit by-product	64.2	[52]
Guava by-product	89.8	[52]
Date seeds	73.5	[67]
Grape fruit by-product	67.2	[64]
Apricot by-product	72.3	[64]
Pomegranate Peel	56.2	[68]
Pomegranate pomace	43.5	[34]

The data reported refer to the dry weight, but the high amount of water in these by-products must be considered. The freeze-drying or spray-dry operations to remove water have to be considered because of their cost rather than preparing a concentrate with less energy consumption for the preparation.

Moreover, DFs showed widespread use in the food industry when they are incorporated into bakery products by enhancing the digestion, prolonging the freshness and retaining more water. They also improve the texture and provide a desirable resistance to melting of ice cream [61].

2.3. Proteins and Peptides

Proteins are important biomolecules for a good function of the human body, particularly to form muscles [29]. Thus, it has been reported that many health diseases are strongly related to protein deficiency such as Kwashiorkor, Marasmus (energy deficiency), mental disorders, organ failure, oedema and weakness immune system [69].

In more recent diets, especially aimed at athletes or for diseases related to diabetes and the cardiovascular system, increased protein intake plays an important role. It is also to be considered that a greater ecological awareness leads people more and more often to limit the consumption of meat, if not actually not to use it as is the case for vegan people.

The use of plants, fungi and their extracts as meat substitutes have become increasingly important in nutrition and satisfies the request for proteins and amino acids, essential for the regular human metabolism. Indeed, fruit by-products have been reported to be an important source of proteins and peptides (Table 3). These latter are generally obtained by the hydrolysis of proteins [10].

Table 3. Protein content in some fruit by-products.

Fruit by-Product	**Protein (%)**	**References**
Orange by-product	5.2	[52]
Passion fruit by-product	12.6	[52]
Guava by-product	2.1	[52]
Date seeds	6.0	[67]
Pomegranate peels	12.9	[70]
Pomegranate pomace	11.1	[34]
Apple Pomace	4.8	[71]
Apple Peel	3.2	[63]
Mango peel	4.3	[72]
Banana Peel	7.0	[73]
Orange juice by-product	18.9	[70]
Orange Pomace	9.8	[74]
Orange Peel	6.8	[75]
Citrus peel	4.5	[76]
Grape fruit by-product	5.8	[13]

In comparison with vegetables, it has been reported that the oil isolated from hempseeds is mainly composed of polyunsaturated fatty acids, particularly linoleic (ω-6) and α-linolenic (ω-3) acids, whereas globulin (edestin) and albumin were found to be the major proteins [77]. The by-product resulted from canola oil extraction (Canola meal) is very rich in proteins (up to 50%), whereas canola seeds contain about 26% of protein. The protein content of canola meal, which consists mainly of napin and cruciferin, permits its use for human food and animal feed [78].

Marcet et al. reported that raw rice bran and raw soybean contained high amounts of peptides, 75% and 50% of the total protein content, respectively, whereas the amount of recovered amino acids from these two by-products was 5% of the total protein content. Peptides were also isolated from soy pulp with a percentage of 35% from the total dry matter [79].

Leuk leaves showed high crude protein content (19.4% on dry matter basis) with a total amino acid content of 14.1% (mainly Leu and Lys, 11.6 and 8.2 mg/g dry matter, respectively), while protein content in parsley was 17.0% from dry matter in which the percentage of essential amino acid was 40%. The most abundant ones were Leu and Lys, 12.4 and 8.3 mg/g dry matter, respectively [80].

2.4. Lipids

Lipids, water-insoluble molecules, are in essential components for the human organism. They play an important physiological and biochemical rolein the function of the human body, such as energy storage (fats and oils), structural components of biological membranes (phospholipids and sterols), electron carriers, enzyme cofactors, light-absorbing pigments, hydrophobic anchors for proteins and emulsifying agents in the digestive tract [81][82]. Besides their important nutritional role in the human diet, lipids are also exploited as food ingredients, thus improving texture, mouthfeel and flavour of new formulations [83]. Indeed, due the increasing demand for vegetable oils, the interest was oriented to the possibility of exploiting new oil sources with higher amount of polyunsaturated fatty acids. In this context, fruit by-products, particularly seeds, have been reported to be a potential alternative for lipids production. Several fatty acids were isolated from various fruit by-products such as linoleic acid, linolenic acid, palmitic acid, palmitoleic acid, oleic acid, lauric acid, myristic acid, stearic acid, lignoceric acid, arachidic acid, erucic acid [83].

Table 4 present the lipid content in various fruit by-products.

Table 4. Lipid content in some fruit by-products.

Fruit by-Product	**Lipid (%)**	**References**
Orange juice by-product	8.4	[70]
Pomegranate peel	3.2	[70]
Pomegranate by-product	4.0	[84]
Passion fruit by-product	8.0	[52]
Guava by-product	1.2	[52]
Apple Pomace	4.2	[85]
Apple Peel	10.1	[63]
Berry pomace	20.2	[36]
Grape fruit pomace	8.5	[86]
Banana Peel	2.0	[87]

Date seeds	8.8	[88]

Apple seeds were reported to contain significant amount of lipids (277 g oil/kg apple seeds), in which unsaturated fatty acids were the predominant (89 g/100 g oil). These lipids are mainly linoleic acid (51.2 g/100 g oil), whereas others are palmitic (10.5 g/100 g oil), linolenic (5.6 g/100 g oil), stearic (4.3 g/100 g oil) and oleic acids (4.1 g/100 g oil) [89]. Wild and cultivated berries seeds are also an important source of lipids (14% to 18% of dry matter). Their rich composition in α-linoleic acid and their high content of α- and γ-tocopherols allows them to be beneficial for balancing diet fatty acid composition and skin regeneration [90][91]. Plum seeds are rich in sterol esters and n-3 PUFA (omega-3) [90], whereas the main lipids in passion fruit seeds are stearic acid, palmitic acid, oleic acid and linoleic acid [92].

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