Bioactive Compounds from Food Industry Bioresidues

Subjects: Engineering, Industrial
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With the increasing demand for convenient and ready-to-eat foods, the use of antioxidants and preservative additives in foodstuff formulation is essential. In addition to their technological functions in food, bio-based additives confer beneficial properties for human health for having antioxidant capacity and acting as antimicrobial, antitumor, and anti-inflammatory agents, among others. The replacement of preservatives and other additives from synthetic origin, usually related to adverse effects on human health, faces some challenges such as availability and cost. An opportunity to obtain these compounds lies in the food industry itself, as a great variety of food waste has been identified as an excellent source of high value-added compounds. Large amounts of seeds, fibrous strands, peel, bagasse, among other parts of fruits and vegetables are lost or wasted during industrial processing, despite being rich sources of bioactive compounds. From a circular economy perspective, this work reviewed the main advances on the recovery of value-added compounds from food industry bioresidues for food application. Bioactive compounds, mainly phenolic compounds, have been largely obtained, mostly from seeds and peels, and have been successfully incorporated into foods. Additionally, alternative and eco-friendly extraction techniques, as ultrasound and microwave, have showed advantages in extracting antioxidant and preservatives compounds.

Keywords: bioresidues ; value-added compounds ; antioxidant molecules ; green extraction methods ; food applications

1. Introduction

According to a survey carried out between 2010 and 2011, it is estimated that about one-third of the food produced for human consumption in the world is lost or wasted, which represents ~1.3 billion tons per year [1]. The interest in estimating these values is not new; in 2007, Mahro & Timm [2] carried out a study about the possibilities of using food processing residues as a biomass resource and concluded that, despite the well-established state of food industry, reliable data on the amounts of the generated waste along the distinct processing stages were difficult to obtain.

More recently, this topic has been gaining interest and, in 2018, Corrado & Sala [3] published a review of existing studies on the generation of food waste on a global and European scale. Through this study, variations in food waste were estimated from 194 to 389 kg per person per year worldwide and from 158 to 298 kg per person per year in the EU. Among the reported works, the project FUSIONS (Food Use for Social Innovation by Optimising Waste Prevention Strategies) stands out, with the estimation of food waste generated at an European level [4]. This project was carried out between 2012 and 2016 through the 7th Framework Program of the European Community, and represented a milestone in the accounting of food waste, with the generation of a manual on food waste quantification [5].

The interest in estimating these values is in line with the concern for the reduction of food waste generated worldwide. In the EU, as summarized on the EUbusiness portal [6], the Waste Framework Directive (Directive 2006/12/EC) has been revised through the Directive 2008/98/EC, to encourage the reuse and the recycling of waste materials and to simplify existing legislation, establishing measures to protect the environment and human health. Another action was through the United Nations Sustainable Development Goal 12.3 [7], where member states have pledged to halve per capita global food waste, in retail and consumer levels, by reducing food waste along production and supply chains by 2030.

FAO data [1] reports that in low-income countries, the generation of food waste is bigger during the initial and intermediate stages of the food supply chain. In industrialized countries, on the other hand, more than 40% of food losses occur at retail and consumer levels, despite also occurring at the beginning of the food supply chain in significant quantities. Analyzing data, it is also verified that, in Europe, more than 50% of the production of roots and tubers and ~46% of the production of fruits and vegetables are lost or wasted, considering the edible parts of food products produced for human consumption. The sub-Saharan Africa region has the lowest production volume of fruit and vegetable group, along with North America and Oceania, compared to other five groups of regions in the world (Europe, Industrialized Asia, North Africa, West and Central Asia, South and Southeast Asia, and Latin America), and ~20% of the amount is lost during industrial processing.

2. Value-Added Compounds in the Development of Innovative Food Products

The recovery and valorization of compounds through green methodologies and from bioresidues, adding value to what would be wasted, corroborates the principles of a circular economy [8]. The circular economy is the concept related to the reduction, reuse, and recycling of food losses and wastes along the food supply chain [9]. The use of bioresidues to obtain value-added compounds is a management strategy for waste and food loss, which can contribute to reducing its environmental impacts, minimizing the use of virgin materials, in addition to promoting opportunities for savings, as innovation of products and methods, competitiveness and productivity [9].

Innovation in the food industry through the use of biocompounds not only adds to the circular economy sustainability concept but is also an opportunity to attend consumers' expectations. In fact, consumers' concern for safer and healthier foods is increasing, and food industry is under pressure to offer healthy, convenient, and ready-to-eat foods, able to meet daily nutritional needs, provide pleasure and satiety, and attend to consumers' expectations and safety issues [10][11]. In this scenario, the replacement of synthetic compounds, generally associated with toxicity and allergenic problems, with healthy natural alternatives is increasingly evident [10]. Alongside, the enrichment of products by using compounds with nutritional value is also a growing tendency. The use of agro-industrial residues, rich in bioactive compounds, has been the focus of studies that propose the use of these by-products in the formulation of functional foods [11]. As synthetized in **Table 1**, value-added compounds were recovered from industrial processes wastewater, from commercially unexplored fruits, and industrial processing by-products, and their applicability was verified. Below, some relevant works available in the literature on the valorization of these compounds and practical applications in foodstuff are discussed.

Table 1. Value-added compounds recovery from food waste and its applicability.

Compound(s) of Interest	Source(s)	Benefit for Health	Applicability	Reference
Vitamin D_2	**Surplus mushrooms**	**Antitumoral**	**Food industry**	[12]
Anthocyanins	**Fig peel and blackthorn fruit epicarp**	**Antioxidant and antimicrobial activities**	**Natural purple colorant in pastry products**	[13]
Dietary fiber	**Pumpkin seeds and rinds**	**Nutritional value**	**High fiber bakery product**	[14]
Phenolic compounds	**Peel of camu-camu fruit**	**Antimicrobial potential**	**Yogurt fortification**	[15]
Anthocyanins	**Strawberry tree fruit**	**Antioxidant and antifungal activities**	**Natural colorant in wafers**	[16]
Phenols	**Olive mill wastewater**	**UVA and UVB filter potential**	**UV booster in cosmetics**	[17]
Sugar	**Coffee silverskin and spent coffee grounds**	**N.A.** [1]	**Ethanol production by fermentation**	[18]
Phenolic acids, hydrolysable tannins, flavonoids, and anthocyanins	**Pomegranate epicarp**	**Antioxidant and antibacterial activities**	**Natural colorant and antioxidant in pastry products**	[19]
Phenolic and carotenoid compounds	**Pumpkin peel**	**Antioxidant activity**	**Retard canola oil oxidation**	[20]
Anthocyanins	**Jabuticaba epicarp**	**Antioxidant, antimicrobial, antitumor and anti-inflammatory activities**	**Natural colorant in macarons**	[21]

[1] Not Applicable.

For example, potato peel wastes were valorized as a source of protein and dietary fiber through their addition to cake [22]. The protein and soluble and insoluble fiber contents of the potato peel powders were about 15%, 19%, and 10%, respectively. The cakes enriched with 10% of potato peel flour achieved a percentage of protein improvement of ~17%. Regarding dietary fiber, the soluble fiber content increased from 3.3% in control cake to almost 5% in enriched cakes, and the insoluble fiber content significantly increased from 15.9% (control) to ~22% for cakes with potato peel flour. In addition to improving the nutritional value, the authors reported technological effects: the incorporation of potato peel powder at 5% increased the dough strength and elasticity-to-extensibility ratio.

Grape seeds and apple peels were also valorized as sources of natural antioxidants, especially phenolic compounds, through the fortification of yogurts with these bioresidues powders [23]. In this line, the authors also optimized the extraction conditions, using green solvents, to obtain extracts with high phenolic compounds content from these by-products. In another study, Chen et al. [24] discussed the applications of grape seed extract in food industry as preservative. They proposed the use of the extract as raw material to develop healthy foods as it improves the nutritional value and promotes benefits such as enhancing the body immunity, prevent hyperlipidemia, hypertension, and diabetes; as natural antioxidant and preservative in food, due to its antioxidant and antimicrobial activity; as food film/coating in food packaging, to improve certain functional properties; and as substitute of nitrite and nitrate in meat products, and sulfur dioxide (SO_2) and animal protein in wine making.

Moreover, the ethanolic extracts of apple peels were fractionated and their use for inhibition of fish oil oxidation was studied using the thiobarbituric acid reactive substances (TBARS) assay [25]. The crude and fractionated extracts presented inhibitory effect on fish oil oxidation, where the greatest antioxidant capacity was verified with the fractions containing quercetin glycosides and epicatechin in combination with other polyphenols, such as phloridzin and cyanidin-3-galactoside. The apple peel was also successfully used as prebiotic in yoghurt [26]. Through this study, a probiotic yoghurt fortified with apple peel polyphenol extract was obtained, which can act as natural high-quality antioxidant and bioactive compound.

In another study [27], a green extraction method was used to obtain phenolic compound-rich extracts from olive leaves. The extracts were obtained by solvent-free MAE and presented high antioxidant activity, so they were proposed as having a great potential as functional ingredients for food packaging. In fact, the developed biodegradable films based on carrageenan containing olive leaf extract showed good barrier and mechanical properties, and the total phenolic compounds and antioxidant activity of the films significantly increased with increased concentrations of the olive leaf extract.

Promising antioxidant extracts were also obtained from the peel of eggplant. Horincar et al. [28] used the green method of UAE to obtain a methanolic extract of this by-product. Six anthocyanins were identified in the extract: delphinidin-3-rutinoside, delphinidin-3-glucoside, cyanidin-3-rutinoside, delphinidin-3-rutinoside-5-glucoside, malvidin-3-rutinoside-5-glucoside, and petunidin-3-rutinoside. In a subsequent study [29], the extract was microencapsulated with whey protein and acacia gum, resulting in a purple colored powder. The addition of the eggplant peel powder in a pastry cream allowed a significant increase of total phenolic content and antioxidant activity, which were rather stable over 72 h of storage under refrigeration conditions. The ethanolic extract of eggplant peel was, then, proposed as supplement in beer [30], with the supplemented beer presenting high functional potential and good sensory characteristics, being stable without the incorporation of artificial preservatives.

Anthocyanin-rich extracts from blackthorn epicarp [31] and fig peel [32], obtained by a green optimized extraction method, were proposed as alternative natural colorants. The extracts were incorporated in confectionery products, more specifically "beijinhos" (a typical Brazilian pastry) and doughnut icing. The obtained purple colorant extracts conferred attractive color to the products, improved the texture properties, and significantly increased the antioxidant and antimicrobial activities. In fact, anthocyanins are widely found in many fruits. As reviewed by Albuquerque et al. [33], fruits and their bioresidues are an excellent source of natural compounds, including a wide range of coloring, in addition to bioactive properties and with great potential to be implemented in the food industry as alternative to the use of synthetic additives. Moreover, the bioresidues from food industry of *Morus nigra* L. and *Rubus fruticosus* L., for not presenting adequate size or properties to be marketed, were also studied as sources of anthocyanins [34]. The juices from these fruits were used in the preparation of solid colorants using the spray-drying technique, which resulted in colorants with a great and stable coloring capacity over time and safe for application in the food industry. In another study [35], an anthocyanin-rich extract was obtained from purple and red potatoes and evaluated as natural colorant in a soft drink formulation in comparison with the commercial colorant E163. The extracts showed suitable profiles in the sensory and shelf-life assessments, with high color stability during a 30-day shelf-life. Despite their multiple health benefits, some of these fruits are not used for consumption for not presenting the suitable size or properties to be included in the market, constituting a food industry residue.

Furthermore, as alternative for the use of synthetic additives in food industry, sage (*Salvia officinalis* L.) and basil (*Ocimum basilicum* L.) were exploited for their preservative purposes [36]. For that, extracts were obtained and incorporated into yogurt. The results were very satisfactory, with the extracts presenting antioxidant and antimicrobial activity, without changing the physicochemical and nutritional characteristics of the yogurts and the growth of lactic acid bacteria.

However, there is a wide range of sources to be explored and valued. In the literature, several biowastes were characterized and identified as having great potential for the recovery of value-added compounds, which could be applied in the food industry. Grape (*Vitis vinifera* L. var. Albariño) and mulberry (*Morus nigra* L.) seed pomace was characterized and the first presented high contents of organic acids and phenolic compounds, mainly catechins, while the mulberry seeds revealed to be rich in tocopherols and ellagic acid derivatives. The extracts containing these compounds showed antioxidant and antimicrobial activity and no cytotoxicity on PLP2 cells (a primary culture of porcine liver non-tumor cells), being their use proposed as natural preservative in the food industry. The epicarp of the eggplant fruit (*Solanum melongena* L.) was highlighted by the authors [37] as a potential natural source of coloring compounds for food application, once it is rich in anthocyanins. Cereal by-products from the flour milling industry, more specifically wheat germ, maize bran–germ mixture, rye bran, and wheat bran, were reported [38] as underexploited alternative sources of nutrients and bioactive compound, such as protein and vitamin E.

References

1. Fao, G. Global Food Losses and Food Waste-Extent, Causes and Prevention; United Nations: Rome, Italy, 2011; pp. 1–37.
2. Mahro, B.; Timm, M. Potential of Biowaste from the Food Industry as a Biomass Resource. Eng. Life Sci. 2007, 7, 457–468.
3. Corrado, S.; Sala, S. Food waste accounting along global and European food supply chains: State of the art and outlook. Waste Manag. 2018, 79, 120–131.
4. Stenmarck, Å.; Jensen, C.; Quested, T.; Moates, G.; Buksti, M.; Cseh, B.; Juul, S.; Parry, A.; Politano, A.; Redlingshofer, B.; et al. Estimates of European Food Waste Levels; IVL Swedish Environmental Research Institute: Stockholm, Sweden, 2016.
5. Tostivint, C.; Östergren, K.; Quested, T.E.; Soethoudt, J.M.; Stenmarck, Å.; Svanes, E.; O'Connor, C.L. Food Waste Quantification Manual to Monitor Food Waste Amounts and Progression; Wageningen University: Wageningen, The Netherlands, 2016.
6. EUbusiness Waste Framework Directive. Available online: www.eubusiness.com/topics/environ/waste-framework/ (accessed on 26 January 2021).
7. UN General Assembly. Transforming Our World: The 2030 Agenda for Sustainable Development, Resolution Adopted by the General Assembly on 25 September 2015; United Nations: New York, NY, USA, 2015.
8. Usmani, Z.; Sharma, M.; Awasthi, A.K.; Sharma, G.D.; Cysneiros, D.; Nayak, S.; Thakur, V.K.; Naidu, R.; Pandey, A.; Gupta, V.K. Minimizing hazardous impact of food waste in a circular economy—Advances in resource recovery through green strategies. J. Hazard. Mater. 2021, 416, 126154.
9. de Oliveira, M.M.; Lago, A.; Magro, G.P.D. Food loss and waste in the context of the circular economy: A systematic review. J. Clean. Prod. 2021, 294, 126284.
10. Pereira, J.M.G.; Formigoni, M.; Viell, F.L.G.; Pante, G.C.; Bona, E.; Vieira, A.M.S. Aditivos alimentares naturais emergentes: Uma revisão. In Realidades e Perspectivas em Ciência dos Alimentos; Nogueira, W.V., Ed.; Pantanal Editora: Nova Xavantina, Brazil, 2020; pp. 46–84.
11. Subiria-Cueto, R.; Coria-Oliveros, A.J.; Wall-Medrano, A.; Rodrigo-García, J.; González-Aguilar, G.A.; Martinez-Ruiz, N.d.R.; Alvarez-Parrilla, E. Antioxidant dietary fiber-based bakery products: A new alternative for using plant-by-products. Food Sci. Technol. 2021.
12. Cardoso, R.; Fernandes, Â.; Barreira, J.; Abreu, R.; Mandim, F.; Gonzaléz-Paramás, A.; Ferreira, I.; Barros, L. A Case Study on Surplus Mushrooms Production: Extraction and Recovery of Vitamin D2. Agriculture 2021, 11, 579.
13. Backes, E.; Leichtweis, M.G.; Pereira, C.; Carocho, M.; Barreira, J.C.; Kamal Genena, A.; José Baraldi, I.; Filomena Barreiro, M.; Barros, L.; Ferreira, I.C. Ficus carica L. and Prunus spinosa L. extracts as new anthocyanin-based food colorants: A thorough study in confectionery products. Food Chem. 2020, 333, 127457.
14. Nyam, K.L.; Lau, M.; Tan, C.P. Fibre from pumpkin (Cucurbita pepo L.) seeds and rinds: Physico-chemical properties, antioxidant capacity and application as bakery product ingredients. Malays. J. Nutr. 2013, 19, 99–109.
15. Conceição, N.; Albuquerque, B.R.; Pereira, C.; Corrêa, R.C.G.; Lopes, C.B.; Calhelha, R.C.; Alves, M.J.; Barros, L.; Ferreira, I.C.F.R. By-Products of Camu-Camu as Promising Sources of Bioactive High Added-Value Food Ingredients: Functionalization of Yogurts. Molecules 2019, 25, 70.
16. Jiménez-López, C.; Caleja, C.; Prieto, M.A.; Sokovic, M.; Calhelha, R.C.; Barros, L.; Ferreira, I.C. Stability of a cyanidin-3-O-glucoside extract obtained from Arbutus unedo L. and incorporation into wafers for colouring purposes.

Food Chem. 2018, 275, 426–438.

17. Galanakis, C.M.; Tsatalas, P.; Galanakis, I.M. Implementation of phenols recovered from olive mill wastewater as UV booster in cosmetics. Ind. Crop. Prod. 2018, 111, 30–37.

18. Mussatto, S.I.; Machado, E.M.; Carneiro, L.M.; Teixeira, J. Sugars metabolism and ethanol production by different yeast strains from coffee industry wastes hydrolysates. Appl. Energy 2012, 92, 763–768.

19. Veloso, F.D.S.; Caleja, C.; Calhelha, R.C.; Pires, T.C.S.; Alves, M.J.; Barros, L.; Genena, A.K.; Barreira, J.C.M.; Ferreira, I.C.F.R. Characterization and Application of Pomegranate Epicarp Extracts as Functional Ingredients in a Typical Brazilian Pastry Product. Molecules 2020, 25, 1481.

20. Salami, A.; Asefi, N.; Kenari, R.E.; Gharekhani, M. Addition of pumpkin peel extract obtained by supercritical fluid and subcritical water as an effective strategy to retard canola oil oxidation. J. Food Meas. Charact. 2020, 14, 2433–2442.

21. Albuquerque, B.R.; Pinela, J.; Barros, L.; Oliveira, M.B.P.; Ferreira, I.C. Anthocyanin-rich extract of jabuticaba epicarp as a natural colorant: Optimization of heat- and ultrasound-assisted extractions and application in a bakery product. Food Chem. 2020, 316, 126364.

22. Ben Jeddou, K.; Bouaziz, F.; Zouari-Ellouzi, S.; Chaari, F.; Ellouz-Chaabouni, S.; Ellouz-Ghorbel, R.; Nouri-Ellouz, O. Improvement of texture and sensory properties of cakes by addition of potato peel powder with high level of dietary fiber and protein. Food Chem. 2017, 217, 668–677.

23. Brahmi, F.; Merchiche, F.; Mokhtari, S.; Smail, L.; Guemghar-Haddadi, H.; Yalaoui-Guellal, D.; Achat, S.; Elsebai, M.F.; Madani, K.; Boulekbache, L. Optimization of some extraction parameters of phenolic content from apple peels and grape seeds and enrichment of yogurt by their powders: A comparative study. J. Food Process. Preserv. 2020, 45, e15126.

24. Chen, Y.; Wen, J.; Deng, Z.; Pan, X.; Xie, X.; Peng, C. Effective utilization of food wastes: Bioactivity of grape seed extraction and its application in food industry. J. Funct. Foods 2020, 73, 104113.

25. Sekhon-Loodu, S.; Warnakulasuriya, S.N.; Rupasinghe, H.V.; Shahidi, F. Antioxidant ability of fractionated apple peel phenolics to inhibit fish oil oxidation. Food Chem. 2013, 140, 189–196.

26. Ahmad, I.; Khalique, A.; Shahid, M.Q.; Rashid, A.A.; Faiz, F.; Ikram, M.A.; Ahmed, S.; Imran, M.; Khan, M.A.; Nadeem, M.; et al. Studying the Influence of Apple Peel Polyphenol Extract Fortification on the Characteristics of Probiotic Yoghurt. Plants 2020, 9, 77.

27. Da Rosa, G.S.; Vanga, S.K.; Gariepy, Y.; Raghavan, V. Development of biodegradable films with improved antioxidant properties based on the addition of carrageenan containing olive leaf extract for food packaging applications. J. Polym. Environ. 2020, 28, 123–130.

28. Horincar, G.; Enachi, E.; Stănciuc, N.; Râpeanu, G. Extraction and characterization of bioactive compounds from eggplant peel using ultrasound—Assisted extraction. Ann. Univ. Dunarea Jos Galati Fascicle VI Food Technol. 2019, 43, 40–53.

29. Horincar, G.; Enachi, E.; Barbu, V.; Andronoiu, D.G.; Râpeanu, G.; Stănciuc, N.; Aprodu, I. Value-Added Pastry Cream Enriched with Microencapsulated Bioactive Compounds from Eggplant (Solanum melongena L.) Peel. Antioxidants 2020, 9, 351.

30. Horincar, G.; Enachi, E.; Bolea, C.; Râpeanu, G.; Aprodu, I. Value-Added Lager Beer Enriched with Eggplant (Solanum melongena L.) Peel Extract. Molecules 2020, 25, 731.

31. Leichtweis, M.G.; Pereira, C.; Prieto, M.; Barreiro, M.F.; Barros, L.; Ferreira, I.C. Ultrasound as a Rapid and Low-Cost Extraction Procedure to Obtain Anthocyanin-Based Colorants from Prunus spinosa L. Fruit Epicarp: Comparative Study with Conventional Heat-Based Extraction. Molecules 2019, 24, 573.

32. Backes, E.; Pereira, C.; Barros, L.; Prieto, M.A.; Genena, A.K.; Barreiro, M.F.; Ferreira, I.C. Recovery of bioactive anthocyanin pigments from Ficus carica L. peel by heat, microwave, and ultrasound based extraction techniques. Food Res. Int. 2018, 113, 197–209.

33. Albuquerque, B.R.; Oliveira, M.B.P.P.; Barros, L.; Ferreira, I.C.F.R. Could fruits be a reliable source of food colorants? Pros and cons of these natural additives. Crit. Rev. Food Sci. Nutr. 2020, 61, 805–835.

34. Vega, E.; Molina, A.; Pereira, C.; Dias, M.; Heleno, S.; Rodrigues, P.; Fernandes, I.; Barreiro, M.; Stojković, D.; Soković, M.; et al. Anthocyanins from Rubus fruticosus L. and Morus nigra L. Applied as Food Colorants: A Natural Alternative. Plants 2021, 10, 1181.

35. Sampaio, S.L.; Lonchamp, J.; Dias, M.I.; Liddle, C.; Petropoulos, S.A.; Glamočlija, J.; Alexopoulos, A.; Santos-Buelga, C.; Ferreira, I.C.; Barros, L. Anthocyanin-rich extracts from purple and red potatoes as natural colourants: Bioactive properties, application in a soft drink formulation and sensory analysis. Food Chem. 2020, 342, 128526.

36. Ueda, J.; Pedrosa, M.; Fernandes, F.; Rodrigues, P.; Melgar, B.; Dias, M.; Pinela, J.; Calhelha, R.; Ivanov, M.; Soković, M.; et al. Promising Preserving Agents from Sage and Basil: A Case Study with Yogurts. Foods 2021, 10, 676.
37. Silva, G.F.P.; Pereira, E.; Melgar, B.; Stojković, D.; Sokovic, M.; Calhelha, R.C.; Pereira, C.; Abreu, R.M.V.; Ferreira, I.C.F.R.; Barros, L. Eggplant Fruit (Solanum melongena L.) and Bio-Residues as a Source of Nutrients, Bioactive Compounds, and Food Colorants, Using Innovative Food Technologies. Appl. Sci. 2020, 11, 151.
38. Cardoso, R.; Fernandes, Â.; Pinela, J.; Dias, M.; Pereira, C.; Pires, T.; Carocho, M.; Vasallo, E.; Ferreira, I.; Barros, L. Valorization of Cereal By-Products from the Milling Industry as a Source of Nutrients and Bioactive Compounds to Boost Resource-Use Efficiency. Agronomy 2021, 11, 972.