LIFE SCIENCE REVIEW

Popular Article

Journal homepage: https://lsr.crcjournals.org/

p-ISSN 3117-3535
e-ISSN 3117-3543

Check for updates

Bioactive Components from Fruit and Vegetable By-Products: Extraction, Modification, Functional Properties and Health Benefits

Jayalaxmi Baddi

Department of Food Technology, Faculty of Life and Allied Health Sciences, M. S. Ramaiah University of Applied Sciences, Bengaluru, India

Received 05 July 2023 | Revised 04 August 2023 | Accepted 03 September 2023 | Available Online 01 October 2023

*Corresponding Author: **Jayalaxmi Baddi** | Email Address: **drjayalaxmib@gmail.com**

Citation: Jayalaxmi Baddi (2023). Bioactive Components from Fruit and Vegetable By-Products: Extraction, Modification, Functional Properties and Health Benefits. ***Life Science Review***. **DOI: https://doi.org/10.51470/LSR**

Abstract

Fruit and vegetable processing generates substantial quantities of peels, seeds, pomace, pulp residues, stems, leaves, and other by-products. Although these materials are frequently discarded or used as low-value feed, they contain valuable bioactive compounds, including polyphenols, flavonoids, carotenoids, dietary fibre, vitamins, minerals, essential oils, and other phytochemicals. Their recovery and conversion into functional ingredients can reduce food losses while creating new opportunities for sustainable food production. Conventional solvent extraction has increasingly been complemented by green technologies such as ultrasound-assisted, microwave-assisted, enzyme-assisted, and pressurized-liquid extraction. Chemical, enzymatic, fermentation-based, and encapsulation approaches can further modify extracted compounds and improve their stability, bio-accessibility, and technological performance. Fruit and vegetable by-product-derived ingredients have potential applications in bakery foods, beverages, snacks, meat alternatives, nutraceutical formulations, and functional foods and major bioactive components present in fruit and vegetable by-products, extraction and modification strategies, functional properties, health-related potential, and future opportunities for their sustainable utilization.

Keywords: *Fruit by-products, vegetable by-products, bioactive compounds, green extraction, food waste valorization, functional foods.*

1. Introduction

The processing of fruits and vegetables generates large amounts of residues, including peels, seeds, pomace, pulp, leaves, stems, and discarded tissues. These materials are often treated as waste despite containing significant quantities of nutritionally and biologically valuable compounds [1]. Fruit peels and seeds may contain higher concentrations of phenolic compounds, carotenoids, dietary fibre, and other phytochemicals than edible portions. Similarly, vegetable leaves, stems, skins, and processing residues can retain substantial amounts of antioxidants, minerals, pigments, and fibre. Their recovery provides an opportunity to convert low-value materials into useful food ingredients. The valorization of these by-products is increasingly linked with the circular economy. Instead of disposal, valuable compounds can be recovered and incorporated into food formulations, thereby reducing resource losses and generating additional economic value.

2. Major Bioactive Components

Fruit and vegetable by-products contain diverse classes of bioactive compounds. Polyphenols, including phenolic acids, flavonoids, anthocyanins, and tannins, are among the most extensively investigated. These compounds contribute to antioxidant activity and may influence several physiological pathways. Carotenoids such as β-carotene, lycopene, lutein, and zeaxanthin are important pigments with antioxidant properties. They are particularly abundant in the peels and processing residues of tomato, carrot, pumpkin, mango, and other coloured fruits and vegetables. Dietary fibre is another major component. By-product-derived fibre can contribute to gastrointestinal health while also providing technological functions such as water binding, oil binding, viscosity enhancement, and texture modification. Essential oils, vitamins, minerals, phytosterols, and other compounds further increase the functional potential of these materials.

Table 1. Important bioactive components of fruit and vegetable by-products and their applications

By-product source	Major bioactive components	Functional properties	Potential applications
Citrus peels	Flavonoids, pectin, essential oils, phenolics	Antioxidant, fibre enrichment	Beverages, bakery foods, extracts
Apple pomace	Polyphenols, pectin, dietary fibre	Antioxidant, water binding	Bakery products, fibre ingredients
Grape pomace	Anthocyanins, flavonoids, resveratrol, fibre	Antioxidant, colour	Beverages, bakery foods
Tomato skins/seeds	Lycopene, phenolics, fibre	Antioxidant, pigment	Sauces, functional foods
Mango peels/seeds	Polyphenols, carotenoids, dietary fibre	Antioxidant, fibre enrichment	Beverages, bakery products
Carrot residues	Carotenoids, fibre, phenolics	Antioxidant, colouring	Snacks, bakery products
Pomegranate peel	Polyphenols, tannins, flavonoids	Antioxidant, antimicrobial potential	Extracts and functional foods
Onion skins	Quercetin, phenolics, fibre	Antioxidant potential	Functional extracts

3. Extraction Technologies

The recovery of bioactive compounds is strongly influenced by extraction technology. Conventional solvent extraction remains widely used because of its simplicity, but it can require substantial quantities of organic solvents and energy. Green extraction technologies offer alternatives with improved process efficiency and reduced environmental impact. Ultrasound-assisted extraction uses acoustic energy to enhance mass transfer and facilitate the release of intracellular compounds. Microwave-assisted extraction can accelerate extraction through rapid heating, while enzyme-assisted extraction uses enzymes to disrupt plant cell-wall structures [2]. Pressurized-liquid extraction, pulsed-electric-field treatment, and other emerging technologies can also improve the recovery of specific compounds. Selection of the appropriate technique depends on the chemical characteristics of the target compound, raw material composition, solvent system, temperature, extraction time, and intended application. For food applications, the safety and regulatory suitability of the extraction solvent are particularly important. Water, ethanol, and other food-compatible solvents are therefore increasingly preferred.

4. Modification and Stabilization

Extracted bioactive compounds may be unstable during processing and storage. Phenolics, carotenoids, anthocyanins, and essential oils can undergo oxidation, degradation, or changes in activity when exposed to heat, oxygen, light, or unsuitable pH conditions. Modification approaches can improve the stability and functionality of these compounds. Fermentation may transform complex phytochemicals and increase the accessibility of selected compounds. Enzymatic treatment can release bound phenolics and modify polysaccharides. Encapsulation is particularly useful for protecting sensitive bioactives. Polymeric, lipid-based, protein-based, and carbohydrate-based delivery systems can shield active compounds from environmental conditions and improve their incorporation into beverages and other food matrices [3]. Microencapsulation may also reduce undesirable taste or colour associated with concentrated plant extracts, thereby improving consumer acceptance.

5. Functional Properties

By-product-derived ingredients can provide both nutritional and technological functionality. Dietary fibre can increase water retention, viscosity, satiety potential, and gastrointestinal functionality. Pectin extracted from citrus and apple residues can act as a gelling, thickening, and stabilizing agent. Phenolic-rich extracts can contribute antioxidant activity and may help protect food lipids against oxidative deterioration. Natural pigments obtained from fruit and vegetable residues can provide alternatives to synthetic colourants in selected applications. Protein and fibre-rich fractions can also improve the nutritional density of foods. However, the effect on texture, flavour, colour, and shelf life depends on the type and concentration of the ingredient.

6. Health Benefits

The health-related potential of fruit and vegetable by-products is largely associated with their polyphenols, carotenoids, dietary fibre, vitamins, and other bioactive constituents. Polyphenols can participate in antioxidant and cell-signalling pathways, while carotenoids may contribute to protection against oxidative processes. Dietary fibre can support gastrointestinal function and influence the intestinal microbiota. Fermentation of fibre by colonic microorganisms may produce short-chain fatty acids, which have important roles in intestinal and metabolic physiology [4]. Certain by-product extracts have demonstrated antimicrobial, anti-inflammatory, hypoglycaemic, or lipid-modulating activities in experimental studies. However, these findings should not automatically be interpreted as established clinical benefits. Bioavailability, effective dose, metabolism, and safety must be assessed before specific health claims can be supported.

7. Food Applications

Recovered bioactive compounds and fibre-rich fractions can be incorporated into a wide range of food products. Bakery products are among the most extensively investigated because fruit and vegetable powders can increase dietary fibre and phytochemical content. Functional beverages can incorporate aqueous or encapsulated extracts, while fruit and vegetable residues can be used to develop smoothies, nutrition bars, sauces, soups, and snacks. Natural pigments recovered from processing residues may also have applications as food colourants. Pectin and fibre obtained from fruit residues can serve as functional ingredients in gels,

confectionery products, dairy alternatives, and beverages. Phenolic-rich extracts can potentially be incorporated into foods where antioxidant protection is desirable.

8. Challenges and Future Perspectives

Despite their considerable potential, several challenges must be addressed before widespread commercial utilization. By-product composition varies according to cultivar, geographical origin, maturity, cultivation practices, processing method, and storage conditions. Standardization is therefore necessary for consistent ingredient quality. Safety is another important consideration. Agricultural residues may contain pesticide residues, heavy metals, microbial contaminants, or other undesirable substances. Appropriate raw-material selection, purification, and quality control are essential. High concentrations of phenolics, tannins, or essential oils may also produce bitterness, astringency, or strong aromas. Optimized extraction, purification, blending, and encapsulation can help overcome these sensory limitations. Future research should focus on integrated biorefinery approaches that recover multiple valuable components from the same by-product. Combining green extraction with fermentation, membrane separation, and encapsulation could increase resource efficiency. Life-cycle assessment and techno-economic studies should accompany product development to determine whether proposed valorization systems provide genuine environmental and economic advantages.

9. Conclusion

Fruit and vegetable by-products represent valuable sources of bioactive compounds and functional ingredients rather than simply processing waste. Polyphenols, carotenoids, dietary fibre, pectin, essential oils, vitamins, and other phytochemicals can be recovered and transformed into ingredients for functional foods. Green extraction technologies provide opportunities to improve recovery efficiency while reducing solvent and energy requirements, whereas fermentation, enzymatic modification, and encapsulation can improve bioaccessibility and stability. These ingredients have applications in beverages, bakery products, snacks, sauces, nutraceutical formulations, and other food systems. Nevertheless, variation in composition, safety, sensory characteristics, stability, and economic feasibility remains challenging. Integrated and sustainable valorization strategies supported by rigorous nutritional and clinical evidence could establish fruit and vegetable by-products as important resources for next-generation functional food production.

References

1. Sagar, N. A., Pareek, S., Sharma, S., Yahia, E. M., & Lobo, M. G. (2018). Fruit and vegetable waste: Bioactive compounds, their extraction, and possible utilization. *Comprehensive Reviews in Food Science and Food Safety, 17*(3), 512–531.
2. Chemat, F., Rombaut, N., Sicaire, A. G., Meullemiestre, A., Fabiano-Tixier, A. S., & Abert-Vian, M. (2017). Ultrasound assisted extraction of food and natural products: Mechanisms, techniques, combinations, protocols and applications. *Ultrasonics Sonochemistry, 34*, 540–560.
3. McClements, D. J. (2018). Delivery by design (DbD): A standardized approach to the development of efficacious nanoparticle- and microparticle-based delivery systems. *Comprehensive Reviews in Food Science and Food Safety, 17*(5), 1091–1120.
4. Koh, A., De Vadder, F., Kovatcheva-Datchary, P., & Bäckhed, F. (2016). From dietary fibre to host physiology: Short-chain fatty acids as key bacterial metabolites. *Cell, 165*(6), 1332–1345.
5. Schieber, A., Stintzing, F. C., & Carle, R. (2001). By-products of plant food processing as a source of functional compounds—Recent developments. *Trends in Food Science & Technology, 12*(11), 401–413.
6. Galanakis, C. M. (2012). Recovery of high added-value components from food wastes: Conventional, emerging technologies and commercialized applications. *Trends in Food Science & Technology, 26*(2), 68–87.
7. O'Shea, N., Arendt, E. K., & Gallagher, E. (2012). Dietary fibre and phytochemical characteristics of fruit and vegetable by-products and their potential applications in food products. *Food Chemistry, 134*(2), 1023–1030.
8. Panzella, L., & Napolitano, A. (2017). Natural phenol antioxidants from agro-food wastes: A mini review. *Current Opinion in Food Science, 17*, 67–73.
9. Helkar, P. B., Sahoo, A. K., & Patil, V. J. (2016). Review: Food industry by-products used as a functional food ingredient. *International Journal of Waste Resources, 6*, 3.