CINEFORUM
ISSN: 0009-7039
Special Issue of international conference IMASEE-2026

Antioxidant Potential of Vegetable Peels in Functional Food Development for Improved Public Health..

Mekala Avani[1], Dr. Damini Soni[2]

[1] Research Scholar, Department of Nutrition and Dietetics, NIMS University Rajasthan, Jaipur, Rajasthan, India.
Email: avanimekala@gmail.com
[2] Assistant Professor, Department of Nutrition and Dietetics, NIMS University Rajasthan, Jaipur, Rajasthan, India.
Corresponding Author:
Mekala Avani
Email: avanimekala@gmail.com

Abstract
Food waste has become a critical global concern, with substantial amounts of vegetable peels discarded during household cooking and industrial processing. Although frequently regarded as waste, vegetable peels are valuable sources of bioactive compounds—including antioxidants, polyphenols, and dietary fiber—that exhibit significant nutritional and functional properties. These compounds play a key role in mitigating oxidative stress and may contribute to the prevention of chronic diseases such as cardiovascular disorders, type 2 diabetes, and cancer. This review focuses on the antioxidant potential of commonly discarded vegetable peels and their prospective applications in the development of functional food products. Evidence from previous studies demonstrates that peels from vegetables such as carrots, potatoes, tomatoes, and pumpkins contain notable concentrations of natural antioxidants and other bioactive constituents that enhance nutritional quality. Recent investigations further emphasize the incorporation of vegetable peel powders into diverse food formulations to improve both functional and nutritional attributes. Such strategies not only elevate the health-promoting value of food products but also foster sustainable food systems by minimizing waste and optimizing the utilization of agro-food by-products. Consequently, the valorization of vegetable peels represents a promising approach for advancing functional food innovation, supporting sustainable nutrition, and strengthening public health outcomes.
Keywords: Vegetable peel; valorization; Antioxidants; Functional foods; Food waste utilization; Sustainable nutrition..

Introduction

A person's health and well-being are significantly influenced by dietary habits. The fundamental right to live is closely linked to the right to adequate and nutritious food. The foods individuals consume, along with their eating patterns, directly impact nutritional status, physical and mental health, and overall wellness. Beyond its biological role, food also holds cultural and social significance, influencing behavior and lifestyle patterns [1].

Globally, lifestyle patterns are rapidly evolving, often in ways that negatively affect dietary habits. These changes are evident in both developed and developing nations and are characterized by reduced physical activity and insufficient consumption of vegetables and whole grains. At the same time, there has been a shift toward energy-dense foods with high caloric content, contributing to various health concerns [2].

Concurrent with these dietary shifts, food waste has emerged as one of the most pressing global challenges of the 21st century. The United Nations Environment Programme's Food Waste Index Report of 2022 estimated that approximately 1.052 billion tonnes of food were wasted globally, equivalent to 132 kg per capita. By 2050, global food demand is projected to increase by approximately 55% relative to 2010 levels, driven by population growth, urbanization, and economic development a trajectory that renders the simultaneous reduction of food waste an ecological and economic imperative [16]. Among food waste streams, vegetable processing by-products particularly peels constitute a quantitatively significant fraction, routinely discarded despite harboring a remarkable density of bioactive compounds [3].

Recent research has increasingly focused on plant-based materials as rich sources of antioxidant compounds, particularly polyphenols. A direct relationship exists between total phenolic content and antioxidant activity in fruits and vegetables. Notably, in many cases, waste by-products such as peels, seeds, and stones contain equal or even higher concentrations of these bioactive compounds compared to the edible portions. This highlights their potential as valuable sources of phytochemicals and natural antioxidants. Critically, in many vegetables, peel fractions contain substantially higher concentrations of these bioactives compared to corresponding edible flesh, with peel-to-pulp total phenolic content (TPC) ratios ranging from 2.5- to 6.0-fold across the species reviewed here [4, 15].

Antioxidants are substances that inhibit oxidation processes in both the human body and food systems. Oxidation reactions generate free radicals, which initiate chain reactions that can damage cells. Antioxidants counteract these effects by neutralizing free radicals and preventing further oxidative reactions. While both synthetic and natural antioxidants are used in the food industry, the use of synthetic antioxidants has been reassessed due to potential health risks, including carcinogenic effects [5].

In addition to their nutritional benefits, the utilization of vegetable peels aligns with the principles of sustainable nutrition by reducing food waste and promoting efficient resource utilization within a circular economy framework. Thus, vegetable peels offer a dual advantage by enhancing the nutritional quality of food products while addressing environmental concerns. Vegetable peel valorization is therefore encouraged as a strategy to improve public health outcomes and support sustainability. The objective of this review is to explore the antioxidant, nutritional, and phytochemical potential of vegetable peels in the context of sustainable nutrition [6].

Recent studies further highlight that fruit and vegetable peels such as mango, avocado, grapefruit, and onion contain a wide range of phenolic compounds. Advanced analytical techniques have identified over 170 bioactive molecules contributing to antioxidant capacity, reinforcing their potential application in functional foods and nutraceutical development [7].

PHYTOCHEMICAL COMPOSITION, ANTIOXIDANT ACTIVITY AND HEALTH PROPERTIES OF SELECTED VEGETABLE PEELS

1. Tomato Peel (Solanum lycopersicum)

Tomato peel constitutes 3–5% of fresh tomato weight and is one of the most nutritionally concentrated carotenoid fractions among processed vegetable products. The body can absorb lycopene more effectively from cooked or processed products such as paste or puree than from raw forms. Consuming these foods with dietary fat of approximately 3–5 g enhances the absorption of lycopene. HPLC-based analyses consistently confirm that lycopene content in tomato peel (1.4–2.2 mg/g DW) substantially exceeds that in pulp (0.4–0.8 mg/g DW) [3]. Along with lycopene, tomato peel contains β-carotene, phytoene, phytofluene, and an array of phenolic acids including chlorogenic acid, caffeic acid, ferulic acid, and the flavonoid glycoside rutin. Total phenolic content ranges from 150 to 320 mg GAE/100g DW [7].

The cardioprotective evidence base for lycopene is among the most robust in the plant bioactive literature. A 2022 systematic review by Przybylska and Tokarczyk concluded that consuming one or more servings of lycopene-rich products such as tomato on a daily basis is associated with a greater than 30% reduction in cardiovascular disease risk, with mechanistic effects including reduction of LDL oxidation, suppression of C-reactive protein (CRP), improvement in endothelial vasodilation mediated by increased NO bioavailability, and inhibition of HMG-CoA reductase [21]. Hsieh et al. (2022) documented that lycopene prevents endothelial dysfunction by reducing peroxynitrite-mediated eNOS uncoupling, a key early event in atherogenesis [22]. Guo et al. (2023) demonstrated that lycopene alleviates oxidative stress in human vascular endothelial cells by activating the SIRT1/Nrf2/HO-1 pathway, linking its antioxidant activity to cardiovascular protection [24]. Anticarcinogenic effects have been documented in prostate, lung, breast, and colorectal cancer cell lines, involving cell cycle arrest at G_0/G_1 phase and induction of caspase-dependent apoptosis [5].

Tomato peel has been incorporated into food as peel powder (3–8% in bakery products), lycopene extracts for nutraceutical capsules, and natural antioxidants in meat, sauce, and paste. Bhardwaj et al. (2022) compiled evidence that tomato peel-enriched products consistently demonstrate improved antioxidant profile and extended shelf life [15]. The encapsulation of lycopene in nanostructured lipid carriers and maltodextrin matrices has been shown to overcome its inherent low aqueous solubility and susceptibility to oxidative degradation, achieving retention rates of 75–90% through high-temperature bakery processing [25]. These technologies have advanced tomato peel as a commercially viable clean-label functional ingredient.

2. Potato Peel (Solanum tuberosum)

Potato peels have high global processing scale among vegetable by-products due to their phenolic density and volumetric significance. The potato industry generates approximately 1.2–2.5 million tonnes of peels annually worldwide, with the peel constituting 5–12% of fresh tuber weight. Vescovo et al. (2025) stated that peel fractions contain bioactive compounds 3-5 fold higher than inner flesh, with phenolic content of 200–550 mg GAE/100g DW [16].

The dominant phenolic constituent is chlorogenic acid present at 120–280 mg/100g DW. The flavonoid concentrations in potato peels range from 0.06 to 2.29 mg catechin equivalents (CE)/g DW in white-fleshed varieties, with anthocyanin content reaching up to 1600 mg/100g DW in purple-fleshed cultivars — a substantial phenolic diversity that renders the choice of cultivar a critical determinant of functional value [16]. Zeng et al. (2023) demonstrated that non-extractable polyphenols (NEPPs) constitute 20–40% of total phenolic content in potato peel, with downstream colonic metabolites including hydroxycinnamic acids and phenylpropionic acid derivatives exhibiting systemic antioxidant and anti-inflammatory activity [6]. Arranz et al. (2009) previously established that ignoring NEPPs results in systematic underestimation of the true in vivo antioxidant contribution of potato peel [8].

Vescovo et al. (2025) further noted that ultrasound-assisted extraction (UAE) and microwave-assisted extraction (MAE) achieve superior phenolic recovery from potato peel with reduced solvent consumption compared to conventional extraction a critical consideration for scale-up [16]. Industrial applications of potato peel include peel powder in bakery products (up to 15% substitution level), dietary fiber supplements, pectin-based gelling agents, natural antioxidants for lipid-containing foods, and recently as a protein and bioactive peptide source. Dhingra et al. (2012) demonstrated that 5–15% potato peel fiber incorporation in biscuits increased fiber, ash content, and antioxidant activity while reducing lipid oxidation during storage, confirming dual nutritional and technological value [27]. Potato peel has been extensively studied for its nutrition, global availability, and waste valorization potential, making it one of the most commercially promising functional ingredients.

3. Carrot Peel (Daucus carota)

Carrot peel constitutes 8–15% of the fresh carrot weight and is enriched in lipid-soluble carotenoids, water-soluble phenolic acids, and fermentable dietary fiber. The primary bioactive constituent is β-carotene, which is the most nutritionally significant provitamin A carotenoid in the human diet. β-carotene undergoes enzymatic cleavage by intestinal β-carotene-15,15'-monooxygenase (BCMO1) to yield two molecules of retinol (vitamin A), which is essential for visual transduction, epithelial differentiation, immune competence, and embryonic development [11].

β-carotene concentrations in carrot peel range from 45 to 180 mg/100g DW, consistently exceeding values for the inner cortical tissue. Additional carotenoids include α-carotene, lutein, and zeaxanthin — the latter two selectively accumulated in macular tissue and associated with protection against age-related macular degeneration (AMD). Phenolic compounds encompass chlorogenic acid, caffeic acid, p-coumaric acid, and luteolin glycosides, collectively conferring TPC of 180–400 mg GAE/100g DW with DPPH inhibition of 60–75% [11]. The bioavailability of carotenoids from carrot peel is strongly modulated by food matrix disruption through thermal processing and homogenization, which ruptures chromoplast structures and enhances micellarization, and by co-ingestion of dietary fat, which is required for efficient lymphatic absorption of lipid-soluble compounds [3].

The dietary fiber fraction of carrot peel is a compositionally heterogeneous mixture of pectin, cellulose, hemicellulose, and lignin. Carrot peel pectins, with degrees of methylesterification (DM) between 50–70%, function effectively as prebiotics in the colon and are selectively fermented by Lactobacillus and Bifidobacterium species to produce short-chain fatty acids [12]. Carrot peel powders have been successfully incorporated as muffins, cakes, crackers, extruded snacks, and beverages at 5–10% substitution, consistently improving fiber and β-carotene content; sensory evaluation studies confirm acceptable organoleptic properties at ≤7% incorporation [12].

4. Pumpkin Peel (Cucurbita spp.)

Pumpkin peel is rich in carotenoids (β-carotene, α-carotene, lutein, zeaxanthin), phenolic acids (caffeic acid, ferulic acid, chlorogenic acid, sinapic acid), pectin (8–18% DW), and insoluble dietary fiber. The vivid orange-yellow coloration characteristic of Cucurbita species reflects the high carotenoid density with total carotenoids ranging from 150–350 mg/100g DW, and contributes substantially to antioxidant activity in lipid-phase systems [7].

Beyond gelling functionality, pumpkin peel pectin functions as a prebiotic, enhancing colonic populations of Lactobacillus acidophilus and Bifidobacterium species, thereby supporting gut microbiota health [3]. Sagar et al. (2018) confirmed that carotenoid-rich peel fractions from Cucurbita species demonstrate significant radical scavenging activity attributable to the combined action of carotenoids and hydroxycinnamic acid derivatives [3]. Mechanistic evidence supports the role of pumpkin peel bioactives in metabolic health management. Anti-obesity effects mediated through suppression of adipogenic transcription factors (PPARγ, C/EBPα) and increased expression of thermogenic genes (UCP-1) have been reported in adipocyte differentiation models, positioning pumpkin peel as a functional ingredient of particular relevance in formulations targeting metabolic syndrome and associated chronic disease risk [2]. Granato et al. (2020) highlighted that carotenoid-rich plant by-products such as pumpkin peel represent promising candidates for functional food development given their multifunctional bioactivity profiles [2]. Bhardwaj et al. (2022) further confirmed the feasibility of peel incorporation across multiple food categories with consistent evidence of improved functional parameters [15].

5. Onion Peel (Allium cepa)

Onion peel is the most phytochemically potent among the vegetable peels. Total phenolic contents range from 520 to 1800 mg GAE/100g DW values 5 -6 fold higher than the edible bulb and DPPH IC_{50} values of 0.3–0.9 mg/mL place it among the most antioxidant-active plant by-products [3, 10]. Its bioactivity is attributable primarily to the extraordinary accumulation of quercetin glycosides in the outer dry skin layers, where concentrations of 1200–2000 mg/100g DW have been reported [10, 11]. Anti-inflammatory effects are mediated through inhibition of COX-1/2, lipoxygenase, and phosphodiesterase [10]. Kumar et al. (2022) conducted a comprehensive study of onion peel bioactivity and functional applications confirming its nutraceutical potential across cardiovascular, metabolic, and inflammatory disease contexts [10]. A clinical study reported that consumption of 200 g onion peel-enriched bread by 14 healthy volunteers resulted in measurable increased blood antioxidant activity, providing direct evidence for onion peel as a functional food ingredient [10]. Wang et al. (2025) demonstrated a approximately 7-fold enrichment of quercetin, rosmarinic acid, and myricetin from crude onion peel extracts using macroporous resin, enhancing both antioxidant and anti-inflammatory potency in the recovered fraction a promising industrial purification strategy [17]. Green extraction advances have further expanded the technologies for onion peel valorization. Enzyme-assisted microwave-assisted extraction (MAE) combining pectinase, hemicellulase, and cellulase with microwave treatment yielded quercetin concentrations of up to 107.48 mg/g from rose onion peel (Lorzadeh et al., 2025) a more than 12-fold improvement over conventional ethanol extraction using GRAS-compatible green solvents and minimal processing steps [14]. These findings highlight the critical importance of extraction methodology selection in determining the functional value of onion peel-derived ingredients for food applications.

6. Brinjal (Eggplant) Peel (Solanum melongena)

The deep purple-to-black outer skin of brinjal is biochemically distinguished by its extraordinary concentration of anthocyanins. The predominant compound, nasunin, is a complex acylated anthocyanin unique to eggplant that has attracted sustained and intensifying scientific interest since Kuroda and Wada first isolated it in 1933 and its structure was definitively characterized by Sakamura et al. in 1963. A review by Alighadri et al. (2024) designated nasunin as among the most structurally complex and biologically significant anthocyanins in the plant kingdom, cataloguing its antioxidant, neuroprotective, cardioprotective, antidiabetic, and antiangiogenic properties [23].

Noda et al. (2000) demonstrated that nasunin at concentrations as low as 1 μM significantly protected against lipid peroxidation of rat brain synaptosomes ($p<0.001$), positioning it as a candidate neuroprotective agent relevant to Alzheimer's disease and other age-related neurodegenerative conditions [13]. Lorzadeh et al. (2025) documented in a systematic review of RCTs that regular intake of anthocyanin-rich foods improves cognitive performance, verbal learning, working memory, and executive function across age groups, highlighting the clinical relevance of nasunin-rich foods for neurocognitive health [14].

Alighadri et al. (2024) further documented that nasunin at 10 μM suppressed microvessel outgrowth in ex vivo assays and inhibited human umbilical vein endothelial cell (HUVEC) proliferation in a dose-dependent manner without affecting HUVEC chemotaxis or tube formation, suggesting selectivity for antiproliferative effects relevant to angiogenesis-dependent diseases including solid tumors [23].

Beyond nasunin, brinjal peel contains substantial concentrations of chlorogenic acid (30–120 mg/100g FW), caffeic acid, delphinidin-3-glucoside, and delphinidin-3-rutinoside. TPC ranges from 300 to 680 mg GAE/100g DW, with DPPH inhibition of 72–90%, significantly exceeding corresponding pulp values [3]. Applications of brinjal peel leverage both bioactivity and coloration; peel-derived anthocyanin extracts function as natural food colorants in beverages, confectionery, and dairy products [22]; peel powder has been incorporated into extruded snacks and chips (4–10% substitution); and the pH-dependent chromatic range of anthocyanins provides additional functionality as a visual pH indicator in intelligent food packaging systems which is a novel application with substantial commercial potential.

7. Beetroot Peel (Beta vulgaris)

Beetroot peel is distinguished by its unique betalain pigment class nitrogen-containing compounds subdivided into betacyanins, principally betanin and isobetanin; and betaxanthins, principally vulgaxanthin I and vulgaxanthin II [19]. Beetroot peel consistently harbors betalain concentrations 25–40% higher than the edible root flesh, driven by the concentration of chromoplasts and betalain biosynthetic machinery in the outer epidermal and sub-epidermal cell layers.

Kanner et al. (2001) demonstrated that betanin is the most effective betalain inhibitor of linoleate lipid peroxidation, attributing its exceptional activity to its electron-donating capacity and ability to neutralize highly reactive radicals targeting cell membranes [28]. TPC in beetroot peel ranges from 250 to 600 mg GAE/100g DW with additional contributions from ferulic acid, caffeic acid, hydroxybenzoic acids, and flavonoids [19]. The interaction of betalains with phenolic compounds, vitamins C and E, and betaine creates synergistic antioxidant activity which exceeds that predicted from individual compound analyses.

The antihypertensive and cardiovascular effects of beetroot bioactives are mediated through two pharmacologically complementary pathways [19, 20]. A 2022 systematic review and meta-analysis by Benjamim et al. across multiple RCTs of beetroot juice in hypertensive patients found mean reductions in systolic blood pressure (SBP) of approximately 3–9 mmHg and diastolic blood pressure (DBP) of approximately 1–2 mmHg reductions of sufficient magnitude to reduce ischemic heart disease mortality by 7–10% and stroke mortality by 10% based on established epidemiological dose-response relationships [20].

Fermentation of beetroot peel-derived ingredients has emerged as a promising processing strategy. Clifford et al. (2015) confirmed that lactic acid fermentation creates an acidic environment that stabilizes betalain pigments against thermal and oxidative degradation, while microbial enzymes improve the bioaccessibility of bound phenolic compounds [19]. These multimodal functionalities, combined with vibrant natural pigmentation and clean-label appeal, establish beetroot peel as one of the most commercially promising among all vegetable peel by-products.

SUMMARY TABLE

Vegetable Peel	Primary Bioactive Compounds	TPC (mg GAE/100g DW)	DPPH IC_{50} / FRAP	Key Functional Benefits	Food Applications
Tomato	Lycopene, β-carotene, Chlorogenic acid, Rutin	150–320	IC_{50}: 1.2–2.8 mg/mL; High FRAP	Antioxidant, anti-inflammatory, cardioprotective, anticarcinogenic	Sauces, pastes, nutraceutical extracts, natural colorants
Potato	Chlorogenic acid, Gallic acid, Caffeic acid, Rutin, Dietary fiber	200–550	IC_{50}: 0.8–1.5 mg/mL; Very high FRAP	Antioxidant, antimicrobial, anticarcinogenic, prebiotic	Bakery products, fiber supplements, natural antioxidant systems

Vegetable Peel	Primary Bioactive Compounds	TPC (mg GAE/100g DW)	DPPH IC_{50} / FRAP	Key Functional Benefits	Food Applications
Carrot	β-carotene, Luteolin, Caffeic acid, Pectin	180–400	IC_{50}: 1.5–3.2 mg/mL; Moderate-High FRAP	Pro-vitamin A, immune support, skin health, vision protection	Snacks, bakery products, beverages, functional flours
Pumpkin	α/β-carotene, Lutein, Pectin, Caffeic acid, Ferulic acid	160–380	IC_{50}: 1.8–3.5 mg/mL; Moderate FRAP	Gut health, cholesterol reduction, anti-obesity, antioxidant	Fiber-enriched bakery, functional food ingredients, pectin extraction
Onion	Quercetin, Kaempferol, Isorhamnetin, Protocatechuic acid, Ferulic acid	520–1800	IC_{50}: 0.3–0.9 mg/mL; Exceptionally high FRAP	Potent antioxidant, antihypertensive, cardioprotective, anti-inflammatory	Natural preservatives, antioxidant extracts, nutraceuticals, bread fortification
Brinjal (Eggplant)	Nasunin (delphinidin-3-rutinoside), Chlorogenic acid, Caffeic acid, Delphinidin glucosides	300–680	IC_{50}: 0.6–1.4 mg/mL; High FRAP	Neuroprotective, cardioprotective, antiangiogenic, lipid-lowering, antioxidant	Natural colorants, functional snacks, nutraceutical extracts, smart packaging
Beetroot	Betanin, Vulgaxanthin I & II, Ferulic acid, Caffeic acid, Dietary nitrate	250–600	IC_{50}: 0.7–1.6 mg/mL; High FRAP	Antioxidant, antihypertensive, hepatoprotective, anti-inflammatory, vasodilatory	Natural food colorants, functional beverages, supplements, fermented products

TPC = Total Phenolic Content; GAE = Gallic Acid Equivalents; DW = Dry Weight; FW = Fresh Weight. IC_{50} = concentration inhibiting 50% DPPH radical scavenging. Values are approximate ranges compiled from peer-reviewed literature [3, 7, 10, 14, 16].

COMMERCIALIZATION CHALLENGES

Although vegetable peels are potential sources of bio active compounds, several challenges remain for their commercialization. One of the biggest challenge being availability and consistency of raw materials. Fresh vegetable peels are highly perishable because of their high moisture content which requires immediate stabilization for preventing microbial spoilage and degradation of bioactive compounds. Few other differences also exists like cultivation, growing conditions industrial processing which result in differences in phytochemical composition making standardization difficult for large scale production. Another challenge is industrial application of of green house technologies like ultrasound-assisted extraction, microwave-assisted extraction, supercritical fluid extraction, and deep eutectic solvent-based extraction have demonstrated improved recovery of bioactive compounds under laboratory conditions. Largescale implemenation remains limited due to high equipment costs, process optimization requirements and also lack og techno economic evaluations. Development of cost effective and scalable extraction technologies is essential for commerical production.

Stabilizing bioactive compounds during processing and storage remain as a major concern. Lysopene, anthocyanins, betalins, β-carotene, and quercetin are some compounds sensitive to light, heat, oxygen and pH which reduces their functional property. Encapsulation technologies improve stability and bio-availability, but their industrial feasibility and cost effectiveness need further investigation. There’s been a demand for clean label and and natural ingredients but peel derived functional ingredients show altered color, flavour, texture of foods as consumer associate vegetable peels as waste so the acceptance and perception remains concerned. Economic feasibility of peel derived vegetables are concerning as studies focus on extraction efficiency and antioxidant activity whereas comprehensive techno-economic analyses covering production, processing, quality control, and commercialization are scarce. Future research should integrate scientific, economic, consumer based approach for commercialization of vegetable peel derived functional ingredients.

REGULATORY PERSPECTIVES

Commercialization of vegetable peel derived derived functional ingredients require compliance with food safety regulations. In India, the Food Safety and Standards Authority of India (FSSAI) regulates the use of functional foods and nutraceutical ingredients. Peel powders dervied from vegetables can be incorporated into food products, concentrated extracts and novel ingredients which require safety evaluation and scientific evidence for approval. International regulatory agencies like European food safety Authority (EFSA) United states food and drug administration (FDA) require evidence on safety, quality, efficacy of functional ingredients before commercialization. At European union for peel derived ingredients with health claims require extensive scientific documentation whereas in United States ingredients should comply with Generally recognized as safe (GRAS) and health related claims require scientific substantiation. Future research should focus on standardized processing protocols and development of regulatory frameworks which support safe and effective use of vegetable peel derived functional ingredients.

CONCLUSION

Vegetable peels, which are often discarded as agricultural and processing waste, are biochemically rich with antioxidant, anti-inflammatory, antimicrobial, neuroprotective, cardioprotective, and antidiabetic properties. The cardioprotective and anticarcinogenic effects of lycopene-rich tomato peel support greater than 30% CVD risk reduction in meta-analyses. Potato peels are rich in phenolic compounds with strong antioxidant activity. Carrot peels provide provitamin A and pectin which acts as a prebiotic. Pumpkin peel contains carotenoids and pectin which support metabolic health. Onion peel has very high quercetin content with proven antioxidant effects backed by clinical studies. Brinjal peel contains nasunin, an anthocyanin with neuroprotective and antiangiogenic properties. Beetroot peel betalains and dietary nitrate together show antioxidant and blood pressure-lowering effects in hypertensive individuals. Focusing on vegetable peel development will help unlock the full benefits of using them for functional food development, human health, and environmental sustainability. Future research should focus on standardizing extraction methods, conducting more human clinical trials, and developing regulatory frameworks to facilitate the commercial incorporation of vegetable peel-derived ingredients into functional food products...

References

1. Monterrosa EC, Frongillo EA, Drewnowski A, de Pee S, Vandevijvere S. Sociocultural influences on food choices and implications for sustainable healthy diets. Food Nutr Bull. 2020;41(2 Suppl):59S–73S. doi:10.1177/0379572120937705
2. Granato D, Barba FJ, Bursać Kovačević D, Lorenzo JM, Cruz AG, Putnik P. Functional foods: Product development, technological trends, efficacy testing, and safety. Annu Rev Food Sci Technol. 2020;11:93–118. doi:10.1146/annurev-food-032519-051708

3. Sagar NA, Pareek S, Sharma S, Yahia EM, Lobo MG. Fruit and vegetable waste: Bioactive compounds, their extraction, and possible utilization. J Food Sci Technol. 2018;55(10):3876–3887. doi:10.1007/s13197-018-3338-3
4. Moo-Huchin VM, Moo-Huchin MI, Estrada-León RJ, et al. Antioxidant compounds, antioxidant activity and phenolic content in peel from three tropical fruits from Yucatan, Mexico. Food Chem. 2015;166:17–22. doi:10.1016/j.foodchem.2014.05.127
5. Pathak PD, Mandavgane SA, Kulkarni BD. Fruit peel waste: Characterization and its potential uses. Curr Sci. 2017;113(3):444–454.
6. Zeng Y, Zhou W, Yu J, Zhao L, Wang K, Hu Z, Liu X. By-products of fruit and vegetables: Antioxidant properties of extractable and non-extractable phenolic compounds. Antioxidants (Basel). 2023;12(2):418. doi:10.3390/antiox12020418
7. Zhang Y, et al. Comprehensive profiling of phenolic compounds in fruit and vegetable peels using LC-MS/MS. Front Sustain Food Syst. 2024;8:1469635. doi:10.3389/fsufs.2024.1469635
8. Arranz S, Saura-Calixto F, Shaha S, Kroon PA. High contents of nonextractable polyphenols in fruits suggest that polyphenol contents of plant foods have been underestimated. J Agric Food Chem. 2009;57(16):7298–7303. doi:10.1021/jf9016652
9. . Kaur A, Singh R, Srikanth K, Bhattacharyya S. Antioxidant potential of potato peel: influence of variety and processing. J Food Sci Technol. 2019;56(4):2273–2282. doi:10.1007/s13197-019-03714-1
10. Kumar M, Tomar M, Potkule J, et al. Onion (Allium cepa L.) peel: A review on the extraction of bioactive compounds, its antioxidant potential, and its application as a functional food ingredient. J Food Sci. 2022;87(9):3751–3769. doi:10.1111/1750-3841.16297
11. Xu DP, Li Y, Meng X, et al. Natural antioxidants in foods and medicinal plants: Extraction, assessment and resources. Int J Mol Sci. 2017;18(1):96. doi:10.3390/ijms18010096
12. Singh B, Bhardwaj A, Singh J, Kaur A. Peel flour fortification in functional food development: Recent advances and future perspectives. Discov Food. 2025;5:12. doi:10.1007/s44187-024-00274-4
13. Noda Y, Kneyuki T, Igarashi K, Mori A, Packer L. Antioxidant activity of nasunin, an anthocyanin in eggplant peels. Toxicology. 2000;148(2–3):119–123. doi:10.1016/S0300-483X(00)00202-X
14. Lorzadeh E, Weston-Green K, Roodenrys S, et al. Microwave and enzyme-based green combinatorial process for the improved extraction of quercetin from rose onion peel. Ind Crops Prod. 2025;224:Article 119902. doi:10.1016/j.indcrop.2025.119902
15. Bhardwaj K, Najda A, Sharma R, et al. Fruit and vegetable peel-enriched functional foods: Potential avenues and health perspectives. Evid-Based Complement Altern Med. 2022;2022:8543881. doi:10.1155/2022/8543881
16. Vescovo D, Manetti C, Ruggieri R, et al. The valorization of potato peels as a functional ingredient in the food industry: A comprehensive review. Foods. 2025;14(8):1333. doi:10.3390/foods14081333
17. Wang C, et al. Macroporous resin recovery of antioxidant polyphenol compounds from red onion (Allium cepa L.) peel. Antioxidants (Basel). 2025;14(2):145. doi:10.3390/antiox14020145
18. Mazinani S, et al. Optimization of bioactive compound extraction from eggplant peel by response surface methodology: Ultrasound-assisted solvent qualitative and quantitative effect. Antioxidants (Basel). 2022;11(11):2103. doi:10.3390/antiox11112103
19. Clifford T, Howatson G, West DJ, Stevenson EJ. The potential benefits of red beetroot supplementation in health and disease. Nutrients. 2015;7(4):2801–2822. doi:10.3390/nu7042801
20. Benjamim CJR, Porto AA, Valenti VE, et al. Nitrate derived from beetroot juice lowers blood pressure in patients with arterial hypertension: A systematic review and meta-analysis. Front Nutr. 2022;9:823039. doi:10.3389/fnut.2022.823039
21. Przybylska S, Tokarczyk G. Lycopene in the prevention of cardiovascular diseases. Int J Mol Sci. 2022;23(4):1957. doi:10.3390/ijms23041957
22. Hsieh MJ, Huang CY, et al. Cardiovascular disease and possible ways in which lycopene acts as an efficient cardio-protectant against different cardiovascular risk factors. Molecules. 2022;27(10):3235. doi:10.3390/molecules27103235

23. Alighadri T, Tabibiazar M, Mohammadi M, Jahanban-Esfahlan A, Amarowicz R. Nasunin, an amazing chemical constituent in eggplants (Solanum melongena L.): A review of its major properties and health-promoting effects. ACS Food Sci Technol. 2024;4(1):16–35. doi:10.1021/acsfoodscitech.3c00582
24. Guo W, Huang D, Li S. Lycopene alleviates oxidative stress-induced cell injury in human vascular endothelial cells by encouraging the SIRT1/Nrf2/HO-1 pathway. Clin Exp Hypertens. 2023;45(1). doi:10.1080/10641963.2023.2205051
25. Carvalho MRCG, de Camargo SS, Chorilli M. Lycopene: From tomato to its nutraceutical use and its association with nanotechnology. Trends Food Sci Technol. 2022;122:251–262. doi:10.1016/j.tifs.2021.10.026
26. Sonia NS, Mini C, Geethalekshmi PR. Vegetable peels as natural antioxidants for processed foods – A review. Agric Rev. 2016;37(1):35–41. doi:10.18805/Ar.v37i1.9262
27. Dhingra D, Michael M, Rajput H, Patil RT. Physico-chemical characteristics of dietary fibre from potato peel and its effect on organoleptic characteristics of biscuits. Journal of Agricultural Engineering. 2012;49:25–32. Available from: https://krishikosh.egranth.ac.in/server/api/core/bitstreams/343c9e27-f2ec-4c5a-8827-300403d4d255/content
28. Kanner J, Harel S, Granit R. Betalains: A new class of dietary cationized antioxidants. J Agric Food Chem. 2001;49(11):5178–5185. doi:10.1021/jf010456f