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Waste to wellness: Valorizing plant peel waste for functional and nutritional improvement of restructured meat products

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Close to one-third of all food produced is wasted. The quest, therefore, for sustainable solutions to address the situation has never been more urgent. An oft-overlooked source of this waste is the fruit and vegetable by-products, such as peels, discarded at the consumer, retail, and other food service levels. Including all parts of fruits and vegetables, this fruit and vegetable waste constitutes close to 16% of the total food waste and contributes approximately 6% to global greenhouse gas emissions (Râpă et al., 2024). Plant peel waste (PPW) represents a literal treasure trove of various phytochemicals and bioactives such as polyphenols, carotenoids, pectin, proteins, phytosterols, dietary fiber, flavonoids, and anthocyanins (Lau et al., 2021). Many of these, for instance, pectins and proteins, can be utilized to improve the functional attributes of various food products. Research regarding the underpinning mechanisms and utilization of these biopolymers in the context of food and nutritional applications is gaining increasing focus.

Similarly, restructured meat (RM) products offer a sustainable pathway for the mitigation of meat processing waste streams. RM products involve the utilization of low-value or usually underutilized carcass cuts, such as trimmings and/or by-products, which are otherwise discarded, to formulate comparatively higher value products (through reorganization and binding) resembling intact muscle (Samad et al., 2024). However, RM products such as nuggets, sausages, and patties often face challenges associated with both quality and safety, such as oxidation, texture variations, and water holding capacity, as well as microbial risk factors (stemming from disassembly and subsequent reassembly of trimmings from a diverse range of meat cuts with their own unique microfloral populations, and greater surface area for bacterial proliferation) (Patel et al., 2023). These issues can compromise both the shelf life and nutritional value of RM products. Various components isolated from PPW can be leveraged through their integration with RM products, potentially helping meat industries turn waste into wellness by enhancing product quality and safety, improving nutritional and health attributes, and addressing global sustainability challenges.

Benefits of plant peel waste-derived functional components

Pectins are well-recognized for their polyelectrolytic and hydrogel-forming attributes, which, in turn, can significantly influence the chemical composition, organoleptic properties, and broad-term acceptability of food products (Tsirigotis-Maniecka et al., 2024). PPW-derived multifunctional pectins, owing to their excellent gelling properties, can function as ready-to-use biomaterials for the development of active gel matrices or microencapsulated systems incorporated with natural antimicrobials (bacteriocins and bacteriostatics), and by virtue of application as controlled/sustained release mechanisms in RM products, improve the shelf life and storage stability of these products by inhibiting the growth of spoilage and pathogenic bacteria (Çavdaroğlu et al., 2022).

Another possibility is to harness the potential of PPW-derived proteins for developing composite gel matrices by blending these proteins into pectin-based film matrices. Through positive interactions with pectins within the gel matrices, proteins have been shown to form stronger networks by way of cross-linking and covalent/non-covalent interactions, imparting improved mechanical and emulsification stability under varying environmental conditions, such as temperature and pH (Gawkowska et al., 2018). Therefore, the gelling properties of these biopolymers can reinforce each other, creating more cohesive structures and manifesting in the form of improved stability (under storage), efficacy of bioactivity delivery capabilities, versatility, and biocompatibility of active gel matrices (Ma

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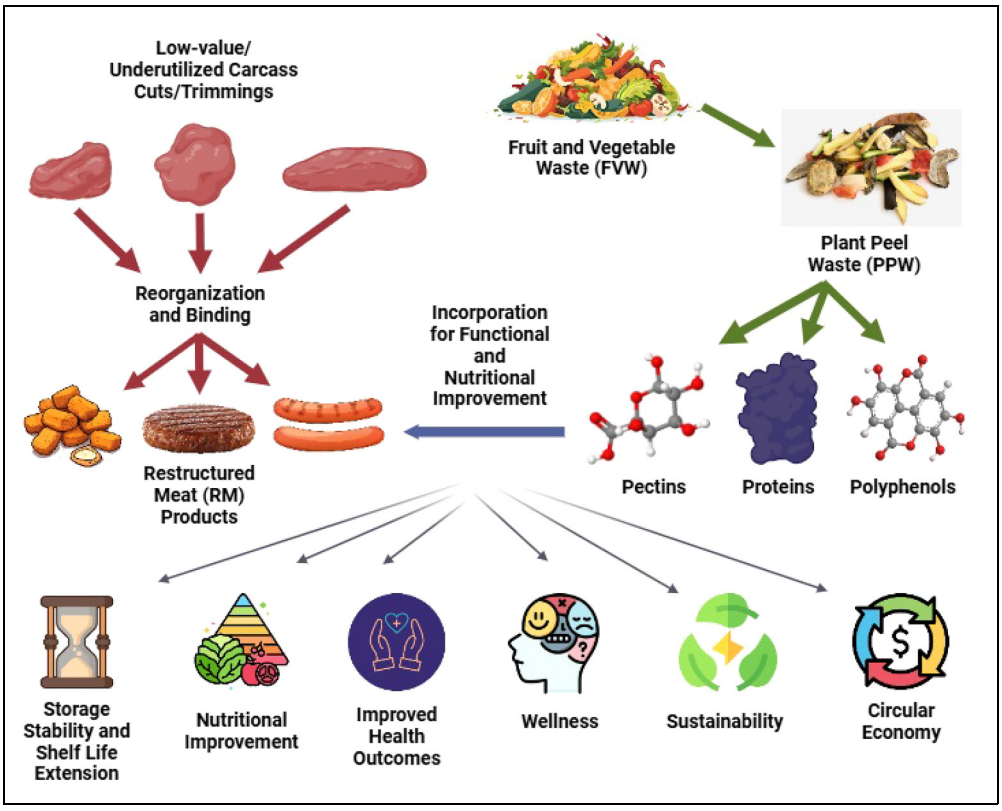

Figure 1. Transforming waste into wellness through valorizing plant peel waste to improve the functional and nutritional attributes of restructured meat products.

and Chen, 2023). PPW-derived proteins can also contribute to increased consumer acceptability of RM products by mimicking the fibrous texture attributed to conventional meat products (by imparting chewiness and a satisfying mouthfeel) (Jang and Lee, 2024). Moreover, owing to their excellent emulsification properties, PPW-derived proteins play a significant role in binding fat and water, improving the finished RM product's juiciness, flavor retention, and mouthfeel and thereby enhancing consumer experience (Ren et al., 2024).

Utilization of PPW-derived components for extending the shelf stability and storage duration of RM products under chilled and refrigerated conditions also minimizes food waste in meat processing streams by reducing spoilage of these products (as a consequence of microbial activity and oxidative deterioration) (Olvera-Aguirre et al., 2023; Awad et al., 2021). PPW-derived components such as polyphenols also add a human health dimension by way of inhibiting the growth of pathogenic bacteria in RM products, for instance, *Salmonella enterica*, *Escherichia coli* O157: H7, and *Campylobacter jejuni* (Beya et al., 2021). Driven by changing consumer preferences and technological developments, the market for RM products is experiencing significant growth trends, with the end of 2023 projections valuing it at USD 5 Billion and a compound annual growth rate of 18% between 2023 and 2033 (Dinani et al., 2022). Therefore, food safety risk factors such as pathogenic bacteria can contribute to the increased incidence of foodborne diseases and adverse nutrition and health outcomes. In addition, PPW-derived proteins can enhance the protein content, nutritional value, and overall dietary quality of the RM products. PPW-derived pectins are also notable for their antioxidant, antimicrobial, anticancer, and immunomodulatory attributes, and their incorporation into RM products offers viable long-term health benefits (Bhardwaj et al., 2022).

In conclusion, the integration of PPW into RM products (Figure 1) has excellent potential, not only in terms of supporting a circular economy model and sustainable production practices (by reducing the environmental footprint of the meat industry) (Doria et al., 2021) but also in considerable functional (product quality, and improved microbial safety), nutritional, and health benefits. Continued research is also required in green extraction methods and regulatory frameworks to enhance the clean label credentials of RM products. This will also serve for improved alignment with the achievement of the sustainable development goals (SDGs) aimed at considerable reductions in global food loss and waste (SDG 12) and fostering sustainable production and innovation (SDG 9) through building resilient infrastructure, and responsible production and consumption habits.

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