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Exploring the potential of mango byproducts in the development of functional foods: A comprehensive review

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Abstract
Fruits with high acceptance worldwide, mangoes, known for their characteristic aroma, flavor, nutritional abundance, and antioxidant property, belong to one of the most appreciated tropical fruits. Unfortunately, a great source of environmental turmoil and economic reasons, around some by-products like peel, seed, and kernel may be discarded. This work thus reflects the potential of many bioactive compounds that are included in mango by-products, which are being harnessed in the manufacture of functional foods. This article reviews studies published in recent years, focusing on the nutritional compositions, antioxidant activity, and possible health benefits of mango residues and by-products, as well as their use in functional food. The findings reveal a good opportunity to convert mango by-products into value-added ingredients capable of promoting human health and well-being, with an added attraction of providing a sustainable method to reduce food wastages and, hence, an increase in food functionality. Being among the most consumed tropical fruits worldwide, mango processing generates ample quantities of wastes, including peels, seeds, kernels, and pulp residues. The byproducts hold bioactive compounds, polyphenols, carotenoids, and dietary fiber, which hold great potential for health benefits and sustainable food innovation. This review discusses the nutritional and functional properties of mango byproducts and their use in some functional foods, along with the importance of integrating these byproducts into sustainable food systems. Key challenges and future research directions are discussed to exploit the full potential of mango byproducts.

Keywords: Mango byproducts, functional foods, bioactive compounds, sustainability, health benefits

1. Introduction
Mangifera indica is a mango variety cultivated in large areas worldwide, with production exceeding 55 million tons a year. Over the years, numerous cultivars of mango have been evaluated for their physico-chemical characteristics, providing insights into their suitability for various product preparations (Megha *et al*., 2022; Bhusari *et al*., 2025) [122, 123]. Thus, the processes to make mangoes into edible products, especially juice, create serious wastes with peelings, seeds, and pulp residues constituting 40-50 percent of the fruit's weight. Such byproducts are dumped into the environment, causing pollution and are economically unfavourable at the same time (Kučuk *et al*., 2024) [52].
Mango, *Mangifera indica*, often called "The King of Fruits," is very popular across the world because of its nutritional value. It is one of the most commonly consumed tropical fruits cultivated in a number of areas of the world, with India being the foremost producer (Lauricella *et al*., 2017) [53]. Second to its brilliant flavour is the gush of sweet, juicy goodness that emanates from the fruit's flesh, while a bulk of by-products formed during high processing (peelings, seeds, and kernels) go untried. However, the disposal of mango biowaste is a growing problem due to the increasing production of this material (estimated to be around 75000 mT worldwide). From an environmental perspective, it is vital to reuse the plant byproducts produced by the agro-food industry (Tirado-Kulieva *et al*., 2022) [124]. There are many years of talking waste about these byproducts; new studies are now being pursued into their potential as a basis for the development of functional foods.
Mango byproducts are rich in bioactive compounds having antioxidative, anti-inflammatory, and antimicrobial actions. These properties are useful in developing functional foods that address contraindications of such actions and promote health. Processing food with mango

byproducts is also considered an environmentally friendly approach, which is something essential in sustainable development and circular economy paradigms.

Preserving an environmentally sustainable food system has become important against food waste and for the health of the environment (Willett *et al*., 2019) [125]. Many food production processes are resource-intensive; hence, from the viewpoint of waste management, need for value addition to by-products so that they are put to effective use. Integrating by-products into functional foods can serve to lessen environmental degradation while providing an economic platform at the same time (Comunian *et al*., 2021) [18].

Functional foods are foods that confer additional health benefits beyond basic nutrition, perhaps in maintaining health or contributing to reducing the risk of chronic diseases. Due to increased interest in functional foods, all kinds of biologically active compounds obtained from natural sources are now in the limelight since they are said to contribute to better health outcomes. Mango by-products, especially mango peel and seeds, may find utility as functional foods since they carry nutrients such as fibres, vitamins, polyphenols, and antioxidants.

Objectives

1) Analyze the nutritional and functional properties of mango byproducts.
2) Highlight their health benefits and applications in functional food development.
3) Discuss processing, sustainability, and economic considerations.
4) Identify challenges and propose future research directions.

2. Composition and nutritional profile of mango byproducts

Mango powdering involves various plant parts, such as peels, seeds, and kernels. All of these byproducts have a different chemical composition, hence presenting different possibilities in the manufacture of functional foods.

2.1 Mango peel

Mango peels are rich in dietary fibre, polyphenols, carotenoids, and flavonoids and roughly 11% dietary fibre, which is valuable for gut health and blood sugar regulation. Polyphenols also combine with mango peels as an excellent source of antioxidant agents such as mangiferin, quercetin, and kaempferol (Zhou *et al*., 2017) [121].

Likewise, the carotenoids exhibited by the mango peel, especially β-carotene and lutein, impart antioxidant capacity, and they might possess a good margin of application in improving vision and alleviating oxidative stress. Polyphenols present in mango peel exhibit anti-inflammatory, antimicrobial, and anticancer activities, which also add to the value of the peel for use in functional food products.

2.1.1 Bioactive compounds

Mango peel is full of polyphenols, carotenoids, flavonoids, and dietary fibre. Polyphenols such as mangiferin have been attributed with strong antioxidant and anti-inflammatory properties, while carotenoids are said to have an additional provitamin A activity according to, Baddi *et al*. (2015) [8], Muralidhara *et al*. (2019) [72], Jain and Sankaran (2004) [102].

2.1.2 Antioxidant and antimicrobial properties

The antioxidant capacity of mango peel helps it combat oxidative stress. The antimicrobial properties make it a natural food preservative & recent investigations have also pointed out its potential use as a functional coating on fruits and vegetables for shelf-life extension (Koirala *et al*., 2024) [51]. Several studies have also established these findings (Baddi *et al*., 2015; Muralidhara *et al*., 2019; Jain and Sankaran, 2004) [8, 72, 102].

2.2 Mango seed and kernel

2.2.1 Nutritional composition

Most proteins, lipids, and dietary fibres are found in mango seeds. The kernel oil is held to contain fatty acids and tocopherols essential for good skin and cardiovascular health (Berardini *et al*., 2005; Mutua *et al*., 2016; Das *et al*., 2022; Choudhary *et al*., 2023) [129, 34, 20, 16].

2.2.2 Phytochemicals and health-promoting compounds

They are rich in phenolic contents, which, among other things, have antidiabetic, anticancer, and cholesterol-lowering properties, according to Ajila *et al*., (2010) [127], Baddi *et al*., (2015) [8], Jain and Sankaran (2004) [102] and Kučuk *et al*., (2024) [52].

2.2 Mango seeds

Mango seeds are another valuable by-product sort of discarded once the fruit is consumed. The mango seed contains starch, proteins, and lipids in large quantities, indicating that it could be a source of bioactive compounds. Studies have revealed that mango seed kernels are rich in polyphenols such as tannins and flavonoids, which exhibit antioxidant, antimicrobial, and anti-inflammatory activities (Sharma *et al*., 2020) [93].

The fat present in mango seeds chiefly comprises unsaturated fatty acids, which may have some beneficial properties like decreasing cholesterol levels and promoting heart health. Further to this, mango seed extracts have also been recorded to enhance insulin sensitivity, thus exhibiting antidiabetic properties.

2.3 Mango kernels

The kernels of mangoes are the central portion of the seed, usually subjected to oil extraction; they contain protein, carbohydrates, fats, and essential fatty acids. Although not well-known, mango kernel oil actually contains good quantities of stearic, oleic, and palmitic acids, which are probably useful in food and cosmetic industries (Mondal *et al*., 2020) [68]. With respect to mango kernel flour, there are studies trying to apply it for gluten-free food since it is primarily higher in fibre and low in glycemic index (Mutua *et al*., 2016; Chand *et al*., 2020; Das *et al*., 2022) [34, 12, 20].

2.5 Mango pulp residues

Residual pulp left after juice extraction is a rich source of vitamins A, C, and E, minerals like potassium and magnesium, as well as other bioactive compounds and is, therefore, an important ingredient in food formulations (Maldonado-Celis *et al*., 2019) [64]. Studies have been made to increase the flavours and nutritional values of yoghurt and ice creams with residual pulp incorporation (Hamdi Darwish *et al*., 2025) [31].

3. Health benefits of mango byproducts

The bioactive compounds in mango byproducts by virtue of their several potential health benefits can be added into functional foods. They can act as antioxidant, anti-inflammatory, anticancer, and antidiabetic agents.

3.1 Antioxidant properties and free radical scavenging

The area of research is promising for exploring mango peel extracts for lipid peroxidation prevention in functional foods. The polyphenols and carotene in mango byproducts neutralise the free radicals, thus lowering oxidative stress and preventing chronic diseases (Sorrenti *et al*., 2023) [105]. The antioxidant activity of mango byproducts is widely studied and more specifically in relation to its general free radical scavenging potential and the associated oxidative stress reduction. Polyphenolic compounds in mango peel and seed exhibit high antioxidant activity that acts on free radicals, thereby protecting cells from damage caused by oxidative stress. This activity is essential for mitigating the impact of chronic disorders, such as cancer, cardiovascular diseases, and neurodegenerative disorders (Gold-Smith *et al*., 2016) [28]. Since the mango peel extracts displayed such potent antioxidant activity, even stronger than the standard antioxidant, ascorbic acid, that brings mango byproducts as a potential candidate towards functional foods for the prevention of oxidative stress-related diseases. Baddi *et al*. (2015) [8], Muralidhara *et al*. (2019) [72], Jain and Sankaran (2004) [102], also reported antioxidant and free radical properties in mango seed and kernel.

3.2 Anti-inflammatory and immunomodulatory effects

Mango byproducts contain bioactive compounds that modulate inflammatory pathways, supporting immune health and reducing the risk of inflammatory diseases (Kim *et al*., 2020) [49]. Mango byproducts also exhibit significant anti-inflammatory properties. Chronic inflammation is associated with "the development of various diseases, including arthritis, diabetes, and heart disease. The polyphenols in mango peels, seeds, and kernels have been shown to inhibit the production of pro-inflammatory cytokines, thus mitigating the effects of inflammation in the body. Studied Anti-Inflammatory Benefits: Versatile Applications in Mitochondrial Bio-Energetics and Exercise Physiology in Mango (*Mangifera indica* Linn)" (Kim *et al*. 2021) [47]. Mango seed extracts reduced inflammatory markers in animal models of colitis, suggesting their potential in functional foods targeting inflammation-related diseases. "In the context of inflammation and immunity, there are fragmented and observational studies relating to the pharmacological activity of *Mangifera indica* L. and its main active component, mangiferin (Márquez *et al*., 2010)" [65].

3.3 Potential in managing chronic diseases

Mango pulp contains anti-inflammatory and cardioprotective properties, and "to examine the effects of fresh mango consumption compared to an isocaloric control snack on body weight" Martin *et al.* (2022) [66]. Mango contains bioactive compounds offering numerous health benefits, including cardio-protective and metabolic properties and the impact of mango fruit and its by-products on human health, emphasising its metabolic syndrome component. Mangos are rich in fibre, vitamins, minerals, and phytochemicals that may offer cardio-protective and immune-boosting benefits. However, their effects on the vasculature and immune system in adults with overweight and obesity remain unclear (Sakaguchi *et al*., 2023) [88].

3.4 Anti-diabetic effects

The high fibre content in mango byproducts slows down the glucose absorption process; thus, it is favourable for glycemic control (O'Shea *et al*., 2012) [76]. They have exhibited the anti-diabetic potential mostly concerning the seeds. Studies have brought insight into how mango seed extracts help regulate blood glucose levels, particularly by improving insulin sensitivity. Tannins and flavonoids from the mango seeds are the major contributors to glucose metabolism modulation. Moreover, research has shown that mango seed oil assumes hypoglycemic activity, thereby becoming a potential treatment in functional foods for diabetes (Sharma *et al*., 2020) [93]. Effects of fresh mango consumption compared with iso-caloric makos suggested that the fruit exerted healthier effects on blood glucose control, inflammation, and antioxidant status (Stamper *et al*., 2023) [106].

3.5 Anti-cancer properties

Phytochemicals present in mango seed and peel possess antiproliferative activities on several cancer cells and may therefore be identified as agents for cancer prevention. Kim *et al*. (2010) [49]. Recently, this subject has gained much importance in terms of the anticancer ability of mango byproducts. Mangiferin has been noted to disrupt many molecular mechanisms in carcinogenesis, such as apoptosis, angiogenesis, and cell cycle regulation. Polyphenols found in mango peels and seeds, such as mangiferin, have been seen to inhibit the proliferation of cancer cells and induce apoptosis in these cells (Shi *et al*., 2016) [97]. There might be other suggestions that mango byproducts can be used as functional foods for cancer prevention.

4. Applications in functional food development

The growing interest in functional foods has led to increased research on the utilization of mango byproducts in the development of health-promoting products. Mango peels, seeds, and kernels have been explored as ingredients in various functional food applications.

4.1 Mango byproducts as ingredients in food formulations

"Various value-added products of mango are used both ripe and unripe, such as mango pulp, mango beverages, dried mango products, mango leather, mango jam, and Mango candy, whereas unripe mangoes are generally used in the form of pickles and chutneys, etc. The mango bar was prepared with dry sugar, citric acid and KMS from frozen Alphonso mango pulp and subjected to physico-chemical analysis and organoleptic evaluation" (Parab *et al*., 2014) [1]. The mango pulp and aloe vera gel are used to prepare a palatable syrup (Chaudhary *et al*., 2017) [61]. Singh *et al.* (2020) [103] studied the development of mango jam by using local mangoes and evaluated the sensory evaluation, nutritional values, and shelf life (Munnangi *et al*., 2023) [71].

4.1.1 Powdered peel and seed extracts

Mango peels, due to their high antioxidant and fibre content, have been used in the development of functional beverages, dietary supplements, and the fortification of food products

such as snacks, bakery goods, and smoothies. Mango peel and seed powders are used as natural colourants and flavour enhancers in food products (Ajila & Rao, 2010) [127]. Mango peel powder has been incorporated into products like bread and cookies, providing additional fibre and antioxidants while maintaining desirable sensory qualities (Schieber *et al*., 2001) [91]. Enhance the nutritional value, antioxidant content, and sensory appeal of biscuits, debittered Mango Peel Powder (MPP) was incorporated into the recipe (Parvez *et al*., 2023) [79]. Effort to repurpose mango peel, this study dehydrated it to create Mango Peel Powder (MPP), which was then incorporated into sourdough bread to produce functional breads with enhanced nutritional value (Ajila & Rao, 2010) [127].

4.1.2 Oil and butter from mango kernel

Mango kernel oil and butter are incorporated into bakery items and confectionery for their rich flavour and nutritional benefits (Nadeem *et al*., 2016) [73]. Their use in chocolate production has been explored for enhancing texture and stability. "Mango Kernel Oil (MKO) has lower free fatty acids, carotenoid content and peroxide value, and is usually used without any processing, which is otherwise mandatory for commercial vegetable oils (Muhammad *et al*., 2016) [70]. The chemical composition of mango kernel oil and its meal was characterised for their physicochemical properties, and functional properties of mango kernel meal were also studied" (Sahar, 2018) [86].

4.2 Fortification in food products

4.2.1 Beverages

Mango peel extracts are added to teas and smoothies to enhance antioxidant content (Jahurul *et al*., 2015) [35]. Develop a healthy instant mango drink powder and compare its nutritional facts with commercially available mango drink powder (Akther *et al*., 2020) [4]. Mango byproducts, particularly mango peel extracts, have been incorporated into functional beverages. These beverages offer a combination of antioxidants, vitamins, and fibre, making them an excellent choice for consumers seeking health benefits through easy-to-consume drinks. Mango peel extract has been used to produce antioxidant-rich juices and teas, which could help in reducing oxidative stress and improving overall health. Mahomoodally *et al*. (2021) [63] studied three formulations whey mango beverage prepared with different "whey and mango proportions (sample-1 = 60:20 mL, sample-2 = 65:15 mL, and sample-3 = 70:10 mL). Kandi Sridhar (2021) [38] developed whey-mango-based mixed beverages and characterised their physicochemical properties. Three different formulations were prepared by varying proportions of whey and mango. Tanvir *et al*. (2023) [113] developed a carbonated mango beverage prepared with 10% pulp, 14% sugar and 0.3% citric acid mixed with plain soda water found to have the highest sensory score in sensory evaluation (Barge *et al*., 2023) [9].

4.2.2 Bakery items

Bread and muffins enriched with mango byproducts exhibit improved nutritional profiles. Quality attributes of bread using mango (*Mangifera indica*) peel flour (Hasan *et al*., 2024) [30]. Mango seed flour is a promising ingredient for gluten-free food formulations due to its high fibre content and low glycemic index. Studies have shown that mango seed flour can be used in the production of gluten-free pasta, bread, and cookies, offering not only nutritional benefits but also enhancing the texture and mouthfeel of these products (Chand *et al*., 2020) [12]. Sponge cake prepared by partial substitution of wheat flour with mango pulp and milk powder at different concentrations (control, 35%, 35%, 50% and 50%) and (5%, 10%, 5% and 10%) was investigated for the physico-chemical, nutritional and organoleptic characteristics. Ramya and Anitha (2020) [32] developed a Sliced Bread (SB) enriched with leaf powder from three mango varieties (Kent, Criollo and Edward) and evaluated the total phenolic content, total flavonoid content and antioxidant capacity. The effect of mango leaf powder on the sensory, textural and chromatic parameters of SB was also assessed. Mónica *et al.* (2024) [69] studied fortified bread prepared with the incorporation of Mango Peel Powder (MPP) and Mango Pulp Powder (MPuP). Different concentrations of MPP (2.5%, 5.0%, and 7.5%) and MPuP (7.5%) were added to improve the functional and bioactive properties of bread (Mehadi *et al*., 2024) [30].

4.2.3 Snack bars and cereals

Inclusion of mango seed flour increases the dietary fibre and antioxidant content of snack bars and cereals (Yatnatti *et al*., 2014) [98].

4.3 Development of nutraceuticals and dietary supplements

Mango byproducts are processed into capsules, powders, and extracts for use as dietary supplements targeting specific health outcomes. "Mango seeds of the Totapuri variety were procured from the local food processing industry. Kernels were separated from seeds and processed into flour through various processing steps. Particle size distribution of the flour was studied. The Mango Kernel Flour (MKF) was subjected to chemical analysis (Yatnatti *et al*, 2014) [118] and nutritionally enriched with vitamins and minerals. For this purpose, three products, namely baked atta Mathri, biscuit and biscuit cake were prepared by incorporating 5 to 20 percent level of mango seed kernel flour and further evaluated for their sensory attributes. Chaudhary and Chabra (2023) [15]. Golek mango seeds can be processed into flour as a source of carbohydrates. The research contribution is to analyse the feasibility of Golek mango seed flour based on SNI 3751:2009". Proximate analysis was used to determine the nutritional content of the golek mango seed flour. Anggraini *et al.* (2023) [6].

5. Challenges and future directions

5.1 Processing and standardization

Developing standardised methods for processing mango byproducts is crucial for ensuring consistent quality and efficacy in functional foods (Gupta *et al*., 2022) [29]. Great source to utilise the mango by-products by the processing of different product formation as mango breakfast cereal, mango dried chutney and mango shrikhand (Keshwani & Mishra, 2018) [43]. Composite Maize-Based Porridges (MBP) were formulated by fortifying maize flour with fine-ground mango seed and kernel at different levels (31%, 56%, 81%). The by-products and formulated porridges were characterised for their nutritional composition, mineral content, total phenolic content, and antioxidant capacity. (Maldonado-Celis *et al.* (2019) [64].

5.2 Consumer acceptance and marketability

Educating consumers about the health benefits and environmental impact of mango byproducts can enhance acceptance and marketability. Innovative marketing strategies and appealing product designs are needed to drive consumer interest (Reddeman *et al*., 2019) [84].

5.3 Regulatory and safety concerns

Ensuring the safety and compliance of mango byproduct-based foods with regulatory standards is essential for market success. Comprehensive toxicological studies are necessary to address any safety concerns Berardini *et al*., (2005) [129].

5.4 Research and development

Future research should focus on exploring novel applications of mango byproducts, such as prebiotics and bioactive packaging materials. Collaborations between industry and academia can drive innovation in this field (Fang *et al*., 2025) [22].

Table 1: Nutritional composition of mango byproducts

Nutrient	Mango peel	Mango seed	Mango pulp	References
Protein content	1.6-2.3 g/100g	6-8 g/100g	0.5-1.2 g/100g	Ali & Jamil (2021) [5], Rathod *et al*. (2023) [82-83] and Sun & Li (2022) [108-109]
Carbohydrates	16-28 g/100g	43.6 g/100g	15.6-20.3 g/100g	Kaur *et al*. (2020) [40-42], Rathod *et al*. (2023) [82-83] and Khan & Haider (2020) [44-45]
Fiber	10-15 g/100g	3.5-5 g/100g	3-5 g / 100g	Chandrasekaran & Suresh (2022) [13-14], Leite & Zoghbi (2020) [56-58] and Bera & Sharma (2020) [10]
Fat content	0.2-1 g/100g	4.2-5.4 g/100g	0.4-0.9 g/100g	Kaur *et al*. (2020) [40-42], Sharma & Kapoor (2020) [94-96] and Cui & Lin (2021) [19]
Antioxidant capacity	High	Moderate to High	Moderate	Kaur *et al*. (2020) [40-42], Rathod *et al*. (2023) [82-83] and Khan & Haider (2020) [44-45]
Polyphenol content	6.2 mg/g	1.8-4.2 mg/g	2-4 mg/g	Ali & Jamil (2021) [5], Zha & Zhang (2020) [119-120] and Saraswathi *et al*. (2022) [89-90]
Vitamins	High in Vitamin A, C and E	High in Vitamin E	High in Vitamin C	Chandrasekaran & Suresh (2022) [13-14], Sharma & Kapoor (2020) [94-96] and Kaur *et al*. (2020) [40-42]

Table 2: Antioxidant and health benefits of mango byproducts

Health benefit	Mango peel	Mango seed	Mango pulp	References
Antioxidant activity	High	Moderate	Moderate	Kaur *et al*. (2020) [40-42], Sharma & Kapoor (2020) [94-96] and Khan & Haider (2020) [44-45]
Anti-inflammatory	Significant reduction in inflammation	Inhibition of pro-inflammatory cytokines	Modest anti-inflammatory potential	Chandrasekaran & Suresh (2022) [13-14], Shukla & Yadav (2021) [99-101] and Saraswathi *et al*. (2022) [89-90]
Blood sugar regulation	Improves insulin sensitivity	Helps regulate blood glucose	Modest effect On glucose metabolism	Khan & Haider (2020) [44-45], Shukla & Yadav (2021) [99-101] and Cui & Lin (2021) [19]
Cancer prevention	Inhibits cancer cell growth	Potential anticancer effects	Potential for cancer prevention	Kaur *et al*. (2020) [40-42] and Rathod *et al*. 2023) [82-83]
Cardiovascular benefits	Reduces blood pressure and cholesterol levels	Improves lipid profile	Potential reduction in heart disease risk	Sharma & Kapoor (2020) [94-96], Sun & Li (2022) [108-109] and Rathod *et al*. (2023) [82-83]

Table 3: Fortification of mango as ingredients in different products

Food application	Mango peel	Mango seed	Mango pulp	References
Smoothies & Juices	Added as powder to enhance fiber and antioxidants	Seed powder can be used as a fiber supplement	Incorporated for added vitamin C and fiber	Figueiredo & Silva (2020) [23-24], Saraswathi *et al*. (2022) [89-90] and Kaur *et al*. (2020) [40-42]
Baked Goods (e.g. Muffins, Breads)	Peel powder used to enhance nutritional content formulations	Seed powder used in gluten-free	Pulp residues can be used as a moisture retention agent	Figueiredo & Silva (2020) [23-24], Sharma & Kapoor (2020) [94-96] and Khan & Haider (2020) [44-45]
Snack Bars and Cereals	Mango peel powder added for increased fiber and antioxidants	Mango seed powder incorporated for fiber and protein	Mango pulp residues can be added to fortify cereals	Leite & Zoghbi (2020) [56-58], Bera & Sharma (2020) [10] and Saraswathi *et al*. (2022) [89-90]
Salad Dressings & Oils	Mango peel extract can be used for its antioxidant properties	Mango seed oil used for its high oleic acid content	Not commonly used in oils	Zha & Zhang (2020) [119-120], Cui & Lin (2021) [19] and Rathod *et al*. (2023) [82-83]
Dietary Supplements	Peel extract used in antioxidant and anti-inflammatory supplements	Seed extracts used for glucose regulation and anti-inflammatory supplements	Pulp residues used in fiber-based supplements	Kaur *et al*. (2020) [40-42], Shukla & Yadav (2021) [99-101] and Saraswathi *et al*. (2022) [89-90]

Table 4: Processing methods and stability of bioactives in mango byproducts

Processing method	Mango peel	Mango seed	Mango pulp	References
Heat treatment	Significant degradation of polyphenols	Minor degradation of polyphenols	Decreases vitamin C content	Kaur *et al*. (2020) [40-42], Chandrasekaran & Suresh (2022) [13-14] and Rathod *et al.* (2023) [82-83]
Freeze-drying	Retains most antioxidants and polyphenols	High retention of flavonoids and tannins	Retains carotenoids and fiber	Bera & Sharma (2020) [10], Shukla & Yadav (2021) [99-101] and Ali & Jamil (2021) [5]
Microwave-assisted extraction	High yield of bioactives with reduced solvent use	Efficient extraction of polyphenols	Efficient carotenoid extraction	Lee & Kang (2019) [54-55], Zha & Zhang (2020) [119-120] and Sun & Li (2022) [108-109]
Ultrasound-assisted extraction	Increased extraction of phenolic compounds	Enhanced extraction of oil and antioxidants	Higher carotenoid and vitamin retention	Figueiredo & Silva (2020) [23-24], Sharma & Kapoor (2020) [94-96] and Rathod *et al.* (2023) [82-83]
Supercritical fluid extraction	Optimal for preserving antioxidants and essential oils	Efficient extraction of bioactive compounds	High retention of bioactive compounds	Zha & Zhang (2020) [119-120] and Saraswathi *et al.* (2022) [89-90]

Table 5: Sustainability and economic aspects of mango ingredients used as product preparation

Sustainability aspect	Mango peel	Mango seed	Mango pulp	References
Environmental impact	Reduces waste and carbon footprint	Reduces waste and supports a circular economy	Minimizes disposal issues and landfill waste	Khan & Haider (2020) [44-45], Shukla & Yadav (2021) [99-101] and Tan & Xie (2021) [11]
Economic feasibility	Low-cost byproduct with high market potential	Cost-effective and underutilized byproduct with high potential	Low-cost and readily available byproduct for food industries	Bera & Sharma (2020) [10], Leite & Zoghbi (2020) [56-58] and Saraswathi *et al*. (2022) [89-90]
Market potential	High demand for antioxidant-rich products	Growing interest in functional ingredients	Increasing demand for fiber-rich ingredients	Kaur *et al*. (2020) [40-42], Shukla & Yadav (2021) [99-101] and Chandrasekaran & Suresh (2022) [13-14]
Contribution to circular economy	Strong contribution to waste reduction and product innovation	Supports sustainable product development	Reinforces sustainable food systems	Leite & Zoghbi (2020) [56-58], Kaur *et al*. (2020) [40-42] and Rathod *et al.* (2023) [82-83]

Conclusion

Food byproducts from mangoes, such as peels, seeds, and kernels, are considered potential sources of bioactive compounds exploitable in the production of functional foods. These byproducts present a wide array of health-giving properties, like antioxidants, anti-inflammatory, anti-diabetic, and anti-cancer potential. Hence, they command the interest of any health-oriented food product developer. Consequently, the use of mango byproducts in functional foods is another way to assist in the reduction of food wastage and enrich the nutritional level of common foods.

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