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Review Article

Mango Peel: An Eminent Food Source

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Abstract:

India has been cultivating mangoes for over 4000 years, and among tropical fruits, mango stands out as the most popular dessert globally. The perishable nature of mangoes, characterized by a relatively short post-harvest lifespan, makes it an ideal fruit for processing. Indeed, mango processing generates a significant amount of peel as a by-product. However, this peel, often considered waste, contributes to environmental pollution as landfills. Interestingly the peel has emerged as an eminent and underexplored food source with a multitude of potential benefits. It can be utilized to create valuable post-harvest value-added products. This review systematically examines the nutritional composition, bioactive compounds, and functional properties present in mango peel. The peel of the mango fruit is found to be rich in dietary fibers, vitamins, minerals, and various phytochemicals such as polyphenols and carotenoids, which contribute to its potential health-promoting properties. Additionally, the antioxidant and antimicrobial activities associated with mango peel highlight its potential applications in food preservation and as a natural additive. The review also discusses the potential use of mango peel extracts in the development of functional foods and nutraceuticals. Furthermore, the sustainable utilization of mango peel as a value-added product aligns with the principles of circular economy and waste reduction. This comprehensive exploration of mango peel as a valuable food source underscores the need for further research and development to unlock its full potential, promoting a more sustainable and holistic approach to food utilization.

Key words: by-product; landfills; mango peel; phytochemicals; polyphenols; tropical fruit; value addition

1.Introduction

India has been cultivating mangoes for over 4000 years, and among tropical fruits, mango stands out as the most popular dessert globally. Belonging to the Anacardiaceae family, which includes some deadly poisonous plants, mango is renowned for its delectable taste, characterized by a delightful blend of sweetness and acidity, along with its enticing aroma and high nutritional value. Mango has unique historical, religious and economic value. In the 21st century, mango remains a predominant tropical fruit, maintaining its position as a leading choice for consumers worldwide. In Indian context, it is an important fruit crop ruling both domestic & export market. The mango fruit is classified as drupe encompassing skin as epicarp, pulp as mesocarp, and seed kernels as endocarp. The size and weight of the fruits vary depending on the cultivar and the prevailing growing conditions [1].

Being a useful and delicious fruit, it was the part of culture and religion since long time. Besides, fine taste and good quality it is called as “The king of fruits”. All the parts of mango plant have various uses in India. Both ripe and unripe fruits are used extensively by food processing industry to prepare wide variety of products such as syrup, jam, squash, juice, cereal flakes and toffee etc from ripe mango. Pickles, chutney, slices, amchur, candy, jam, jelly, preserve and squash etc are prepared from unripe mango fruits [2].

Extensive documentation confirms that mango fruits serve as a significant source of micronutrients, vitamins, and various phytochemicals. Furthermore, mangoes contribute essential components such as energy, dietary fiber, carbohydrates, proteins, fats, and phenolic compounds [3].These elements play a crucial role in supporting normal human growth, development, and overall health. The aim of this article is to highlight the nutritional significance of mango peel which otherwise go as a waste during processing and thus contributing to ecological sustainability and nutritional security of the country.

2. Production and Export Aspects

Mango fruits have experienced a remarkable surge in production, trade, and consumption, both on a domestic and international scale. This growth can be attributed to the compelling nutritional benefits offered by these fruits. Currently, mango cultivation is a thriving industry in more than 100 countries across the globe, with production witnessing a steady rise annually in response to the growing demand from consumers. Mangoes are being produced in almost all the continents, with Asia as the leader followed by America and Africa [4].

2.1 Production Statistics

India is the largest mango producer, accounting for 38.6% of the mangoes produced, followed by China, Thailand, Mexico and Indonesia. The other major mango growing countries are Pakistan, Brazil, the Philippines, Nigeria and Egypt. Mango is grown in an area of 5.58 million hectares in the world. India is the largest producer of mangoes with 46.02 and 45.88 per cent of the total world area and production, respectively [5]. In India, Mango is grown in an area of 2.26 million ha with a production of 21.82 million tonnes and productivity of 9.66 tonnes per ha during 2017-18. Major mango-growing states in India include Andhra Pradesh, Uttar Pradesh, Karnataka, Bihar, Gujarat and Tamil Nadu. Uttar Pradesh and Andhra Pradesh are the leading states in mango production with 4.55 and 4.37 million tonnes respectively [5].

2.2 Export Scenario

Mexico is the largest mango exporter in the world, followed by India, Brazil, Pakistan and the Netherlands. Although India is the largest mango producer, it is surpassed by Mexico in terms of mango exports. The export quantity and value of mangoes is about 49.18 thousand MT and 382.34 crore rupees during 2017-18 respectively. The major export destinations of mangoes from India are United Arab Emirates, United Kingdom, Saudi Arabia, Qatar, United States, Kuwait, Oman, Nepal, Baharain, Singapur and others [5].

India has achieved grand success in the export of Indian mangoes to the USA by registering a growth of 19 percent in comparison to the previous fiscal year. India has exported 2043.60MT of Indian mangoes to the USA in the first five months of the current fiscal. With the collaboration of Ministry of Agriculture and Farmers Welfare and APEDA, India exported 22,963.78 MT of mangoes worth USD 48.53 million in 2022-23, while in the current year 2023-24 (April-August), India has exported 27,330.02 MT of mangoes worth USD 47.98 million. Besides the USA, India has exported 43.08 MT of mangoes to Japan, 110.99 MT to New Zealand, 58.42MT to Australia and 4.44MT to South Africa. In the season 2023, India has exported mangoes to 41 countries by exploring new destinations such as Iran, Mauritius, Czech Republic and Nigeria (https://pib.gov.in/PressReleaseIframePage.aspx?PRID=1971931).

2.3 Mango pulp export scenario

India has made a tremendous achievement in the export of mango pulp as compared to the export of fresh mangoes. The country has exported 109501.38 MT of Mango Pulp to the world for the worth Rs. 1189.66 crores/147.60 USD Millions during the year 2022-23. Major export destinations include Saudi Arabia, Netherland, USA, UK and United Arab Emirates. The export earnings from mango pulp are more than the export earnings from fresh mangoes. Chittoor in Andhra Pradesh and Krishnagiri in Tamil Nadu are the two clusters where mango pulp is processed and exported to other countries. Apart from this, few of the processing plants are located in Maharashtra and Gujarat [6].

3. Processing of Mango

Mango fruit contains the highest vitamin A content of 4800 IU among the other fruit crops and is also rich in several other health promoting contents. Renowned for its seasonal abundance, mango faces substantial wastage due to ineffective postharvest handling practices, particularly during peak seasons which further accounts for postharvest losses up to 60–80% of annual production [7]. This loss substantially causes the loss of potential nutritional source of the country. Recognizing the need to minimize the post harvest losses, a promising solution lies in the processing of surplus mango fruits. This approach not only addresses the challenge of postharvest wastage but also extends the consumption of mango beyond its peak season, thereby mitigating the impact of poor postharvest technology on overall production.

Mangoes are valued for their rich flavour and adaptability, and they may be used to make a wide range of commercial goods to suit different tastes. Mango puree is a concentrated, smooth version of the mango pulp that can be used in a variety of culinary applications, including drinks and desserts. Mango slices preserved in syrup provide a delicious treat by retaining the sweetness of the fruit. Made by combining puree and water, mango nectar is a cool drink that tastes just like ripe mangoes. A portable snack with a stronger mango flavour is produced by dehydrating puree to create mango leather, a chewy treat. While canned mango slices offer a practical and long-lasting choice for culinary creations, pickled mangoes yields a savoury and tangy condiment. Mango chutney, a harmonious blend of mangoes, spices, and other ingredients, adds a flavorful dimension to various dishes. Amchur, a tangy mango powder is prepared by the raw mangoes and is used as a taste enhancer in many dishes. These industrial marvels not only showcase the adaptability of mangoes but also ensure a year-round supply of this tropical delight in an array of delightful forms.

The processing of mangoes into these diverse forms allows for the preservation of their rich flavor and nutritional attributes beyond the typical harvesting season. This strategic approach not only addresses the challenge of seasonality but also ensures a consistent supply of mango-based products that cater to the demands of consumers, contributing to the fruit's sustained popularity and economic importance in international markets. In the processing phase, approximately 200,000 tons of food losses are generated, with mango peels constituting up to 24% of this total volume [8]. Specifically during mango processing, byproducts such as the raw and ripe peel as well as kernels are generated, with the peel alone contributing about 15–25% to the total fruit weight [9]. Regrettably, the peel is presently not harnessed for any commercial purposes, leading to its disposal as waste and contributing to environmental pollution as landfills [9-12].

This discarded peel should be recognized as a specialized residue due to its elevated levels of residual phenolics. The presence of these phenolics raises concerns about potential adverse environmental impacts, particularly in inhibiting the seed germination properties of polyphenols [13]. Consequently, industries are faced with escalating costs for the treatment of this waste, emphasizing the pressing need for innovative and sustainable solutions to utilize mango peel effectively and mitigate its environmental consequences. As a result, initiatives have been implemented to increase the value of byproducts produced in the course of mango processing, specifically focusing on biomass [14-16].

4. Mango peel a pack of nutrients

The mango peel, often overlooked in favor of the succulent fruit it conceals, possesses its own unique qualities and potential benefits. Rich in antioxidants, fiber, and essential nutrients, the peel contributes to the overall nutritional profile of the mango. They were also a good source of polyphenols, carotenoids and other bioactive compounds which posses various beneficial effects on human health. Recently, mango peels have attracted considerable attention in the scientific community due to their high content of valuable compounds, such as phytochemicals, polyphenols, carotenoids, enzymes, vitamin E and vitamin C, which have predominant functional and antioxidant properties [10]. Both raw and ripe mango peels exhibited significant amount of protease, peroxidase, polyphenol oxidase, xylanase and amylase activities [10]. Furthermore mango peels are the rich source of dietary fibre, cellulose, hemicellulose, lipids, protein, enzymes and pectin. These valuable compounds are also beneficial for human health [17]. Table 1 comprises the functional and nutritional composition of raw and ripe mango peel.

Content	Quantity in Peel		Reference
	Raw Peel	Ripe Peel	
Protein	1.45-1.76 %	1.76-2.05%	[10]
	-	3.6%	[18]
	0.16g/kg	0.18g/kg	[19]
	-	3.8g/100g	[20]
	-	7.03-8.06%	[21]
	-	2.8%	[22]
Carbohydrates	21.52-26.5%	20.8-28.2%	[10]
	7.36g/kg	7.1g/kg	[19]
	-	86.4g/100g	[20]
	-	8.93-11.45%	[21]
	-	75.7%	[22]
Crude Fibre	3.28-3.8%	5.8-7.4%	[10]
	-	9.33%	[18]
	1.26g/kg	1.45g/kg	[19]
	-	8.9g/100g	[20]
	-	10.92-20.53%	[21]
	-	9.9%	[22]
Moisture	66-70.25%	72.5-75.25%	[10]
	-	4.92% (Peel Powder)	[18]
	0.75g/kg (Peel Powder)	0.62g/kg (Peel Powder)	[19]
	-	3.9%	[20]
	-	59.5-68.88%	[21]
	-	5.9%	[22]
	-	5.19-9.37g/100g	[17]
Fat	2.16-2.49%	2.22-2.66%	[10]
	-	1.23%	[18]
	0.23g/kg	0.32g/kg	[19]
	-	2.6g/100g	[20]
	-	1.51-2.48%	[21]
	-	1.4%	[22]
Ash	1.4-3%	1.16-1.3%	[10]
	-	3.88%	[18]
	0.25g/kg	0.32g/kg	[19]
	-	0.24-0.54%	[21]
	-	4.2%	[22]
Total Startch	1.91g/kg	1.68g/kg	[19]
Polyphenols	20.1-109.7mg/g	9.84-100mg/g	[10]
	-	19.06mg/g	[18]
	102.41mg/g	70.2mg/g	[19]
	-	4.5g/100g	[20]
	-	24.3mg/g	[22]
	-	2032-3185mg/100g	[17]
Flavonoids	33mg/g	29.24mg/g	[19]
Dietary Fibre	44.7-64.13%	63.8-78.4%	[10]
	5.94g/kg	5.68g/kg	[19]
	-	69.86%	[20]
Carotenoids	365-547µg/g	1400-3945µg/g	[10]
	96.91µg/g	160.64µg/g	[19]
	-	5600µg/g	[20]
	-	1.88-4.05mg/100g	[17]
Anthocyanins	215.74mg/g	425.02mg/g	[19]
Vitamin C	188-315µg/g	349-392µg/g	[10]
	109.71mg/g	52.51mg/g	[19]
	-	68.49-84.74mg/100g	[17]
Vitamin E	205-337µg/g	308-509µg/g	[10]
WHC	-	5.08 g H2O/g	[18]
	0.87g/kg	0.36g/kg	[19]
	-	4.3 g H2O/g	[22]
	-	4.68-6.05g/g	[17]

OHC	-	2.02 g Oil/g	[18]
	0.22g/kg	0.18g/kg	[19]
	-	2.2 g Oil/g	[22]
	-	1.66-3.1g/g	[17]
Scavenging Activity	-	93.89%	[18]

(All values are expressed on a dry weight basis)

Table 1: Nutritional composition of mango peel

5. Phytochemical compounds in Mango peel

The peel of fruits is a rich source of antioxidants, carotenoids, catechins, flavanoids, phenolic acids, pectin, mangiferin, quercetin and dietary fibres.

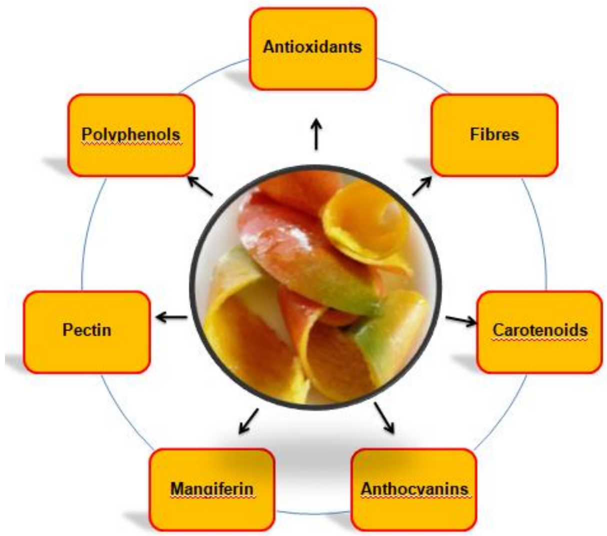

Figure 1: Phytochemical compounds in peel of mango

5.1 Antioxidants

The antioxidant and radical scavenging activities of peels play a significant role in impeding or preventing the oxidation of crucial cellular components such as DNA, proteins, and lipids [23]. This protective function against oxidative stress, underscores the potential health benefits associated with the consumption or utilization of peel extracts. The antioxidant activity in the peel of Uba variety has been studied. The peels exhibit a noteworthy total phenolic content of 57,240 mg/kg of dry matter, constituting approximately 8–6% of the dry matter. This surpasses the phenolic content found in apple peels (3.3% w/w). Notably, the peel contains Mangiferin and Isomangiferin. Additionally, Quercetin 3-O-glucoside was identified in the pulps of both Haden and Uba, with significantly higher concentrations in the Uba peels. The Uba peels are particularly abundant in mangiferin and quercetin glycosides, with contents of 270 and 785 mg/kg of dry matter, respectively. Further analysis also revealed the presence of Kaempferol 3-O-glucoside at a concentration of 35.3 mg/kg of dry matter. The presence of large quantities of flavonols and xanthone glycosides in the peels of Uba cultivar justifies its antioxidant activity [24].

In another experiment, two significant compounds, ethyl gallate and penta-O-galloyl-glucoside, were successfully extracted from mango peels. The research demonstrated the notable ability of these compounds to effectively scavenge hydroxyl radicals, superoxide anions, and singlet oxygen [25]. A group of scientists conducted a study to explore the antioxidant and anti-proliferative properties of both mango peel and pulp. Additionally, they investigated the cytoprotective effects of extracts from mango peel and pulp against oxidative damage induced by H2O2 in a human hepatoma cell line (HepG2). The findings revealed that mango peel contained higher levels of flavonoids and polyphenols compared to the pulp, showcasing robust antioxidant activity. Moreover, the study demonstrated that treating HepG2 cells with mango peel extracts effectively inhibited DNA damage [26]. These results underscore the substantial antioxidant potential of mango peels, suggesting their promising role as a functional food or supplement ingredient. It also highlight the importance of exploring peel-derived compounds for their possible applications in promoting health and preventing oxidative damage to cellular structures.

5.2 Dietary Fibre

Mango peel has been recognized as a valuable source of dietary fiber [27]. The existence of diverse bioactive components and dietary fiber in mango peel, attributing to it antioxidant and free-radical-scavenging properties were studied [28]. Additionally the dietary component plays a crucial role in various physiological processes and is associated with the prevention of conditions such as constipation, hypertension, liver cirrhosis and diabetes [29]. The positive impact of peel-derived dietary fibers on health extends to factors such as intestinal movement; mitigate cancer risk; mineral and glucose absorption in the intestine and immune system regulation [30]. The fibers in mango peel encompass a mixture of chemically diverse substances, including cellulose, hemicelluloses as insoluble fibres and pectins, lignins, gums, and polysaccharides as soluble fibres [31]. Soluble fibers contribute to lowering glucose absorption in the small intestine and reducing blood cholesterol, while insoluble fibers aid in water absorption and regulation of intestinal functions [32].

An experiment was conducted to study the carbohydrate composition and bound phenolics in the dietary fiber of mango peels. The total dietary fiber content was found to range from 40.6% to 72.5%. The major neutral sugars identified in both insoluble and soluble dietary fibers were galactose, glucose, and arabinose. The bound polyphenolic content ranged from 8.1 to 29.5 mg/g, while the flavonoid content ranged from 0.101 to 0.392 mg/g. The reported bound phenolic acids included gallic, protocatechuic, and syringic acids, while kaempferol and quercetin were identified as the major flavonoids in the peels [32]. Gallic acid emerges as the primary phenolic acid bound to dietary fiber in mango peel, with major flavonoids being kaempferol and quercetin; however, their concentrations may vary among different varieties [33]. Following fermentation, polyphenols bound to dietary fibers break down into phenylacetic, phenylpropionic, and phenylbutyric acids. The non fermented, non absorbable polyphenols serve as antioxidants during the scavenging of free radicals and play a role in suppressing the effects of dietary pro-oxidants in the large intestine [34].

The substantial fiber content in mango peel has led to its incorporation into diverse food supplements, enhancing their functional properties [35]. Mango flour exhibited a well-balanced combination of soluble and insoluble dietary fibers, with the total dietary fiber content varying between 3.2 to 5.94 g/kg. The water absorption capacity and oil absorption capacity of mango flours were observed to fall within the ranges of 0.36 to 0.87 g/kg and 0.18 to 0.22 g/kg, respectively [19]. Given the richness of mango peel in dietary fiber and bound phenolics, the study suggests its potential use in the development of functional foods.

5.3 Pectin

In the functional food industry, pectin, classified as a soluble fiber, is commonly sought after as a vital food ingredient [36]. Extractable pectin is used as a food additive and is advocated for its roles in gelling, stabilizing, and thickening processes [37]. In the pharmaceutical industry, pectin finds application in the creation of thin films for drug carriers. Its role as an emulsifier and stabilizer makes it particularly valuable as a gelling and thickening agent, making it highly desirable for applications such as jelly and jam preparation, as well as other household products [14].

Mango peel is a promising reservoir of dietary fibre with 5%–11% pectin depending on variety and extraction method [16, 31 and 32]. Pectin oligosaccharide (POS) is derived from mango peel through enzymatic hydrolysis [38]. Mango peel pectin oligosaccharide is projected to have significant potential as both a prebiotic and a stimulant for the production of total short-chain fatty acids by Bifidobacterium animalis and Lactobacillus reuteri [21]. Short-chain fatty acids play a regulatory role in blood glucose levels, pathogenic bacteria, colonic cancer, mineral absorption, and modulation of the immune system.

5.4 Carotenoids

Carotenoids are fat-soluble pigments that are responsible for the vibrant hues of fruits, ranging from yellow and orange to red. Just like the pulp, the mango peel is also rich in carotenoids, particularly in the form of β-carotene, a precursor to vitamin A [24]. However, there has been relatively less research on the carotenoids present in the peel compared to those in the pulp [39].

The carotenoid content in mature mango peels was discovered to be 4–8 times greater than that in unripe fruit peels [10]. The carotenoid compositions of mango peels were analyzed at different ripening stages across 12 selected colored cultivars. Eight distinct carotenoids were identified, with β-carotene, cis-β-carotene, and violaxanthin isomers emerging as the primary compounds in all cultivars. The research revealed significant variations in carotenoid content based on the fruit color. The highest concentration (31.18 µg/g FW) was observed in the yellow-colored Arka Anmol, while the lowest content (0.74 µg/g) was found in Janardhan Pasand. Yellow-colored Arka Anmol also exhibited the highest concentration of β-carotene (13.01 µg/g FW), and this compound was present in all tested mango cultivars [40]. The study highlighted that carotenoid concentrations generally increase during ripening, with peak levels observed in the yellow-colored stage.

5.5 Anthocyanins

Anthocyanins which are water-soluble pigments responsible for imparting red, blue, and purple hues to fruits, are currently being utilized as natural biocolorants, replacing synthetic colors [41]. Recognized for their positive impact on health, anthocyanins are associated with the prevention of diverse diseases, including cancer, diabetes, and conditions affecting the nervous and cardiovascular systems, thereby contributing to the promotion of human well-being [42-45].

A group of scientists documented the anthocyanin contents in some red colored cultivars [46]. The results showed that Tommy Atkins showed the highest anthocyanin content (3719µg/kg) followed by Heidi (2920 µg/kg), Haden (1694 µg/kg), Kent (507µg/kg), Jose (283 µg/kg), and R2E2 (211 µg/kg). In line with this experiment, the maximum anthocyanin content in the peels of red-colored mangoes (228.2 µg/100 g FW), surpassing levels found in yellow and green counterparts [40]. The primary anthocyanins identified in peels of diverse mango cultivars included cyanidin, pelargonidin, delphinidin, malvidin, petunidin, and peonidin.

5.6 Polyphenols

Polyphenols, a diverse group of naturally occurring antioxidants, have been associated with various health benefits, including anti-inflammatory, anti-cancer, and cardiovascular protective effects. Various polyphenolic compounds include quercetin, kaempferol, catechins, gallic acid, chlorogenic acid, mangiferin, ellagic acid etc. The polyphenol content within the peel varies between 55–110 mg/g dry weight, with elevated levels observed in ripe peels compared to unripe ones [10]. 13 and 12 phenolic compounds were detected in the peel of Pica and Tommy Atkins variety [47]. The peel of Pica mangoes showed also the highest content of phenolics (66.02 mg/100 g FW). Seven phenolic acid derivatives, three procyanidin dimers, and four xanthones (mainly mangiferin and mangiferin gallate) were identified in the peel of Pica variety. In the case of the Uba cultivar from Brazil, the polyphenol content constitutes 6–8% of the dry weight, with the quantities of flavonoids and xanthones in the peel surpassing those in the pulp by 4.6 and 7.3 times, respectively [24].

Among the six xanthone derivatives identified in mango peel, mangiferin (C2-β-D-glucopyranosyl-1,3,6,7-tetrahydroxyxanthone), a type of C-glucosyl xanthone, exhibits numerous pharmacological activities. Notably, mangiferin, along with its isomeric forms (mangiferin + isomangiferin + homo-mangiferin), is present in higher concentrations in mango peel compared to the pulp and seed [48]. The estimated mangiferin content in mango peel is approximately 1.69 g/kg dry weight, and this concentration is influenced by temperature. At elevated temperatures, there is a decrease in mangiferin concentration accompanied by an increase in its derivatives. This transformation process leads to the formation of xanthones from the benzophenone derivative form, contributing to the creation of xanthone C-glycosides in mango peel. One more phenolic compound quercetin 3-Ogalactoside is also present in the peel [49, 50].

5.7 Other Therapeutic potential of Mango peel

The bioactive compounds present in mango peel have been extensively documented for their potential in reducing the risk of various health conditions, including cancer, Alzheimer's disease, cataracts, and Parkinson's disease [23]. Mangiferin, a prominent compound in mango peel, has been specifically associated with a lowered risk of cancer [51]. Additionally, functional compounds such as protocatechuic acids and β-carotene exhibit antimicrobial, anti-diabetic, anti-inflammatory, and anti-carcinogenic properties [35]. Pharmaceutical studies have revealed that gallate-type compounds, exemplified by penta-O-galloyl-glucoside, demonstrate diverse bioactivities, including anti-tumor, antioxidant, anti-cardiovascular, and hepatoprotective effects [52-55]. Moreover, the presence of Penta-O-galloyl-glucoside and ethyl gallate in the peel has been linked to inhibiting tumor growth and reducing the likelihood of heart diseases [56]. The combination of these bioactive compounds underscores the potential health benefits associated with the consumption of mango peel.

6 Mango Peel Flour

The production of flour from industrial byproducts is an alternative method to reduce post-harvest losses [57]. The utilization of fruit peels that do not meet commercial standards helps minimize post-harvest losses, contributing to a more efficient use of agricultural resources. The process involves transforming mango peels, which may otherwise go to waste, into a valuable product with various benefits. Firstly, this method reduces the free water content, leading to an extended time-to-market for the resulting mango peel flour. Simultaneously, the concentration of health-promoting nutrients is enhanced during the production process.

Mango peel flours emerge as noteworthy sources of fiber, providing a valuable dietary component. Moreover, these flours serve as effective carriers for increasing the intake of essential minerals, carotenoids, and ascorbic acid. The composition of peel flours is marvelous, showcasing significant levels of calcium, magnesium, manganese, carotenoids, and antioxidants. Additionally, the flour exhibits a high percentage of large particles, suggesting potential applications in various industries. Notably, the good water retention capacity of mango peel flour further underscores its versatility and suitability for different uses [58]. In essence, the production of mango peel flour not only addresses waste reduction concerns but also yields a nutritionally dense product that can contribute to dietary fiber, minerals, and antioxidants, showcasing its potential as a valuable resource in both culinary and industrial contexts.

7 Industrial Application of Mango peel flour

7.1 Food Industry

Mango peel flour has evolved into a multifaceted ingredient, offering not only gluten-free and nutrient-rich properties but also contributing to the development of innovative and health-conscious food products across a spectrum of culinary applications [19]. Widely incorporated into items such as noodles, bread, sponge cakes, biscuits, and other bakery products, this gluten-free flour serves as a beneficial additive in the food processing industry, contributing both texture and nutritional value. Mango peel is rich in odor-active compounds, making it a valuable source for natural flavors. It can be directly used as a flavoring ingredient or as a source for extracting volatile compounds. The resulting extract itself is suitable for use in the food and cosmetic industries to impart or enhance the mango aroma in products [51, 58 and 59].

The mineral composition of mango peel flour is particularly impressive, boasting high levels of potassium, calcium, magnesium, and iron. Its appearance, resembling Besan (chickpea flour), adds to its appeal in diverse culinary applications. Incorporating this flour enhances the antioxidant activity of these products, attributed to the additional fiber, phenolic compounds, and carotenoids present [51]. Interestingly, when compared to pulp flour, peel flour exhibits greater amounts of potassium and total fibers [58]. Moreover, mango peel flour can serve as a substitute in the production of products like cream, cheese, and yogurt, showcasing its adaptability across various food categories [59].

The mango peel powder (MPP) was introduced into biscuit preparation at varying levels (5%, 10%, 15%, and 20%), replacing wheat flour in an experiment. The incorporation of MPP into the dough resulted in increased water absorption, rising from 60.4% in the control to 67.6% in the dough containing 10% MPP. Additionally, it led to an augmentation in biscuit diameter, thickness, and spread ratio. These outcomes suggest the potential for enhancing both the nutritional quality and antioxidant properties of biscuits through the incorporation of mango peel powders [18]. These results are further in line with the experiment conducted by some other scientists [27], wherein the results showed that wheat flour incorporated with mango peel powder yielded dietary fibre-enriched biscuits with improved antioxidant properties.

Furthermore macaroni products were innovatively enriched with mango peel powder (MPP) at three different levels (2.5%, 5.0%, and 7.5%). The investigation focused on assessing the quality of these products, examining cooking characteristics, polyphenol, carotenoid, and dietary fiber contents, as well as free radical scavenging activity. The results demonstrated that the total dietary fiber, polyphenols, firmness, and carotenoid content of the macaroni increased with the incorporation of mango peel flour. Macaroni incorporated with MPP up to 5% level resulted in products with good acceptability suggesting that the incorporation of mango peel powder can improve the nutritional profile of macaroni without adversely affecting its cooking, texture, or sensory properties [60].

Researchers fortified the nectar with mango peel powder. They developed nectar, with four distinct treatments utilizing different amounts of MPP (0.5, 1, 1.5, and 2 g/100ml). The findings indicated that Treatment 2 (1g/100ml) garnered higher acceptability compared to the other treatments. However, the inclusion of MPP beyond 1g in 100ml of mango nectar led to a decline in the overall acceptability score, as assessed by a panel of judges [61].

Besides mango peel flour, rich in dietary fiber and polyphenols, can serve as a prebiotic to enhance the growth of probiotic strains in the gastrointestinal tract. When added to yogurt, which already contains probiotic strains, it creates a symbiotic yogurt. The chemical composition of mango peel further improves yogurt properties by slowing serum release during acidification, and polyphenols enhance the yogurt's acid-gel network, leading to better viscosity. This makes mango peel flour a promising prebiotic, aiding in the colonization of probiotics in the gut, thereby positively impacting human health [62].

7.2 Pharmaceutical and therapeutic industry

A study was conducted to investigate the in vivo antioxidant properties of mango peels in addressing dyslipidemia and oxidative stress among a group of overweight individuals. The research involved 31 female volunteers aged 25 to 45, all falling within the overweight category with a body mass index (BMI) ranging from 25.0 to 29.9. The findings revealed that the consumption of mango peel powder led to significant reductions in levels of low-density lipoproteins (LDL), cholesterol, triglycerides, urea, and creatinine ($P \leq 0.05$). Conversely, high-density lipoprotein (HDL) levels experienced an increase. Moreover, the levels of thiobarbituric acid reactive substances (TBARS) demonstrated an augmented antioxidant status ($P \leq 0.05$). These results strongly suggest that mango peels exhibit robust potential in managing oxidative stress and dyslipidemia in individuals grappling with obesity [63].

7.3 Other uses

Researchers showcased a groundbreaking method by utilizing the derivative of mango peel extract for the innovative biological synthesis of silver nanoparticles [64]. Their findings indicated that non-woven fabrics infused with these biosynthesized silver nanoparticles exhibited remarkable antibacterial efficacy. The researchers suggested these nanoparticles as a highly promising option for various medical applications. Mango peel can be also used in processing industry for packaging as biodegradable materials [30].

The feasibility of employing ATPS alcohol/salt to purify serine protease on mango peels were investigated [65]. The highest partition coefficient (64.5) and selectivity (343.2) for the serine protease purification value were achieved in an ATPS of 16% (w/w) 2-propanol, 19% (w/w) potassium phosphate and 5% (w/v) NaCl at pH 7.5. They concluded that the serine protease from mango peels could be an excellent choice for applications in the food, detergent, biotechnology and pharmacology industries.

Conclusion

Mango by-products particularly peel, presenting a significant challenge for scientists in terms of recovery and utilization of valuable compounds. Mango peel have been extensively studied and found to be rich sources of health-enhancing substances, including phenolic compounds, carotenoids, vitamin C, and dietary fiber. This study emphasizes the need for comprehensive research not only on compound recovery but also on specific applications to ensure industrial exploitation and product sustainability. Mango peel, identified as a robust source of bioactive compounds and enzymes, could serve as a promising functional food or valuable ingredient in our dietary system. Convenient processing of mango peel could yield useful products, potentially offsetting waste treatment costs and reducing overall production expenses. There is a clear opportunity for isolating these active ingredients and incorporating mango peel into various processed food products, such as bakery items, breakfast cereals, pasta, bars, and beverages, offering both health benefits and economic advantages.

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