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Akshay K Puri
Research Scholar, Department of Food Engineering, College of Food Technology, VNMKV, Parbhani, Maharashtra, India

Dr. BS Agarkar
Associate Professor & Head, Department of Food Plant Operation, College of Food Technology, Maharashtra, India

Mohini Dalve
Research Scholar, Department of Food Engineering, College of Food Technology, VNMKV, Parbhani, Maharashtra, India

Amol Dukare
Research Scholar, Department of Food Engineering, College of Food Technology, VNMKV, Parbhani, Maharashtra, India

Rushikesh Karpe
Research Scholar, Department of Food Processing Technology, College of Food Technology, VNMKV, Parbhani, Maharashtra, India

Shantanu Konde
Research Scholar, Department of Food Engineering, College of Food Technology, VNMKV, Parbhani, Maharashtra, India

Dipali Gajmal
Research Scholar, Department of Food Engineering, College of Food Technology, VNMKV, Parbhani, Maharashtra, India

Corresponding Author:
Akshay K Puri
Research Scholar, Department of Food Engineering, College of Food Technology, VNMKV, Parbhani, Maharashtra, India

Raw mango powder: A sustainable approach for functional and nutraceutical food development

Akshay K Puri, BS Agarkar, Mohini Dalve, Amol Dukare, Rushikesh Karpe, Shantanu Konde and Dipali Gajmal

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Abstract
Mango (*Mangifera indica* L.) is a nutritionally important tropical fruit rich in carbohydrates, dietary fibre, vitamins, minerals, carotenoids, polyphenols, and antioxidant compounds. However, its high moisture content makes it highly perishable, leading to significant post-harvest losses. Dehydration is considered an effective preservation technique for improving shelf life, storage stability, and product utilization. Raw mango powder prepared from unripe mangoes has gained considerable importance due to its high acidity, characteristic sour flavour, lower sugar content, and suitability for drying and instant beverage formulations. This review discusses the nutritional composition of ripe and unripe mango, processing techniques involved in raw mango powder production, and the influence of different drying methods such as hot air drying, spray drying, freeze drying, and microwave-assisted drying on product quality, nutrient retention, and physicochemical properties. The review also highlights major processing challenges including stickiness, hygroscopicity, and caking, along with the potential utilization of mango peel and kernel as sources of dietary fibre, antioxidants, pectin, and functional ingredients. Overall, raw mango powder possesses significant potential in functional food and nutraceutical applications due to its nutritional, sensory, and health-promoting properties.

Keywords: *Mangifera indica*, raw mango powder, drying technologies, physicochemical properties, by-product utilization

1. Introduction

Mango is among the most significant tropical fruits grown across the world and belongs to the family Anacardiaceous under the order Sapindales. It is highly valued for its appealing colour, characteristic aroma, pleasant flavour, and rich nutritional composition. Due to its widespread popularity and versatile use in both fresh consumption and processed products, mango is often regarded as the “king of tropical fruits” (Bhatnagar and Subramanyam, 1973) [9].

India stands as the epicenter of mango's origin, boasting an impressive array of nearly one thousand distinct varieties, each exhibiting unique physicochemical properties and processing characteristics that make them exceptionally well-suited for a wide range of food applications, from fresh consumption to value-added products like juices, pulps, and dried snacks (Sadhu and Bose, 1976; Kalra *et al*., 1981) [39]. Worldwide, mango commands a vital position among tropical fruits, securing the second spot in both production volume and cultivated acreage right after banana, underscoring its economic and agricultural significance in tropical regions (Muchiri *et al*., 2012) [31]. As reported by the Food and Agriculture Organization (FAO, 2022) [16], exports of mango, mangosteen, and guava collectively hit approximately 2.3 million tonnes in 2021, accounting for nearly 29% of the total volume of internationally traded tropical fruits and highlighting the fruit's growing role in global commerce and food security.

Mango is recognized as a highly nutritious fruit and an important dietary source of carbohydrates, proteins, dietary fibre, vitamins, minerals, and other macro- and micronutrients required for proper human growth and physiological functions (Tharanathan *et al*., 2006) [48]. Besides its nutritional importance, mango is also rich in several bioactive constituents such as carotenoids, particularly β-carotene, polyphenols, quercetin, kaempferol, and ascorbic acid, which contribute significantly to its functional and therapeutic value (Shoukat *et al*., 2024; Hussain *et al*., 2024b, c) [42].

These phytochemicals exhibit strong antioxidant, antimicrobial, and anti-inflammatory activities that help in protecting the body against oxidative stress and various chronic disorders. Scientific investigations have further indicated that regular mango consumption may support cardiovascular and vascular health by lowering the expression of adhesion molecules associated with inflammation (Castro *et al*., 2023) [11]. Moreover, diets rich in antioxidant and polyphenolic compounds have been reported to enhance the body's defense mechanisms against several bacterial and viral infections (Djarkasi *et al*., 2021; Hussain *et al*., 2023b) [12]. Owing to its rich nutritional profile and abundance of health-promoting compounds, mango is increasingly being explored as a valuable ingredient in the development of nutraceuticals and functional food products (Albaayit, 2024; Pérez-Meza *et al*., 2024) [4, 35].

Although Mango possesses significant nutritional and therapeutic benefits, its application in functional foods and dietary supplements is still relatively limited when compared with medicinal plant extracts and synthetic nutraceutical formulations (Bahri *et al*., 2021; Lebaka *et al*., 2021) [7, 28]. The majority of commercially available health supplements are marketed as tablets, capsules, or herbal powders, while only a limited number of products incorporate mango as a natural source of bioactive phytonutrients such as carotenoids and polyphenols. Therefore, there is growing scientific as well as industrial attention toward the development of value-added mango-based products, especially nutraceutical formulations and instant beverage powders enriched with functional compounds.

Due to their high moisture levels typically around 85% fresh mangoes are exceptionally perishable and prone to rapid microbial decay and post-harvest damage (Thind *et al*., 2002) [49]. This fragility is underscored by FAO data, which indicates that roughly 21% of global food waste in the produce sector is driven by inadequate handling and logistics (FAO, 2019) [15].

The mango industry is particularly hard-hit, with nearly one-third of all harvested fruit lost annually during various stages of the supply chain, from ripening to retail. Consequently, implementing advanced preservation and processing methods is vital to prolonging shelf life, mitigating economic losses for producers, and minimizing global food waste.

Drying is regarded as one of the oldest, most economical, and widely practiced methods for the preservation of fruits and vegetables. The process of dehydration involves the removal of moisture from food materials, which subsequently reduces water activity and creates unfavorable conditions for the growth of spoilage microorganisms such as bacteria, yeasts, and molds. As a result, drying significantly enhances the storage stability, safety, and shelf life of food products while also reducing post-harvest losses during transportation and storage (Singh *et al*., 2022) [44]. In addition to preservation, drying contributes to a reduction in product weight and volume, thereby lowering packaging and transportation costs and improving handling convenience.

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Mango is extensively processed into a wide range of shelf-stable and value-added products including pulp, juice, nectar, squash, pickles, chutney, fruit leather, canned slices, flakes, and dehydrated powders (Saxena and Arora, 1997) [40]. These processed products not only improve the utilization of seasonal mango production but also provide opportunities for extending product availability throughout the year. Among the different processed forms, mango powder has emerged as a highly promising product because of its convenience, ease of storage, long shelf life, and versatility in food applications. Mango powder is widely utilized as an ingredient in several food formulations such as cakes, bakery products, cereal flakes, fruit bars, confectionery products, instant beverage mixes, dairy products, and ice cream due to its characteristic flavour, colour, and nutritional properties (Akhter *et al*., 2010) [3].

Furthermore, mango powder offers several advantages over fresh mango, including reduced perishability, easier transportation, and better incorporation into dry food systems. The increasing consumer demand for convenient and functional food products has further accelerated interest in the development of dehydrated mango-based ingredients. However, despite its commercial potential, the production of high-quality mango powder remains a technological challenge for the food processing industry. Problems such as stickiness, hygroscopicity, caking during storage, poor flowability, and low reconstitution properties often affect the quality and consumer acceptability of the final product. Therefore, considerable research is being focused on improving drying technologies and formulation techniques to produce mango powder with enhanced solubility, reduced caking tendency, better stability, and rapid reconstitution characteristics suitable for industrial and commercial applications.

While traditional hot air drying is widely adopted for mango preservation due to its low cost and ease of use, it often degrades the fruit's overall quality. Extended exposure to heat can strip mangoes of their essential vitamins, natural pigments, and aromatic profiles (Basulto *et al*., 2014; Nguyen *et al*., 2022). Furthermore, the dehydration process can cause soluble solids and beneficial bioactive compounds to migrate, further compromising the nutritional and sensory value of the final product (Hernández-Ruíz, 2017) [19].

To address these drawbacks, researchers are turning toward more sophisticated drying methods. Technologies such as freeze drying, spray drying, and microwave-assisted drying among others are currently being explored to better preserve the mango's integrity and nutritional density (López & Hincapié-Llanos, 2024).

Mango processing industries produce large amounts of by-products, mainly peels and seeds, which account for about 35-60% of the total fruit weight depending on the cultivar and processing method (Larrauri *et al*., 1996) [27]. These by-products are rich in dietary fibre, carotenoids, vitamin C, phenolic compounds, and bioactive lipids with important nutritional and antioxidant properties (Ajila *et al*., 2007;

Sogi *et al*., 2013) [2, 46]. Mango seed fat has gained attention due to its physicochemical similarity to cocoa butter, making it useful for confectionery and food applications (Jahurul *et al*., 2014a) [22]. Proper utilization of mango by-products can improve resource efficiency, create value-added products, and reduce environmental pollution caused by food waste disposal (Mirabella *et al*., 2014) [30].

Growing consumer interest in nutritious, convenient "functional" foods has sparked the development of fruit-based powders and instant mixes. Because mango powder retains high levels of antioxidants and appealing sensory traits, it is an ideal ingredient for these health-focused beverages. Advancing mango dehydration research is therefore crucial—not only to improve product quality and shelf life but also to reduce waste and support sustainable practices throughout the food industry.

2. Nutritional Composition of Ripe and Unripe Mango

The nutritional composition of mango undergoes significant changes during the ripening process as a result of various biochemical and physiological transformations occurring within the fruit tissues. During ripening, complex carbohydrates such as starch are converted into simple sugars, leading to increased sweetness. Simultaneously, pigment synthesis, cell wall softening, and the formation of flavour and aroma compounds occur, which collectively influence the texture, colour, taste, and overall nutritional quality of the fruit (Yahia, 2011) [51].

2.1 Protein and Fat Content

Both ripe and unripe Mango contain comparatively low levels of protein and fat. The protein content generally ranges between 0.6-0.7 g per 100 g of edible portion, whereas the fat content varies from 0.1-0.4 g per 100 g. Although mango is not considered a significant source of proteins or lipids, it still provides small amounts of essential amino acids and fatty acids that contribute to important metabolic and physiological functions in the human body (Hui, 2006) [20].

2.2 Dietary Fibre

Unripe Mango contains a higher amount of dietary fibre (1.2 g/100 g) compared to ripe mango (0.7 g/100 g). The greater fibre content in immature mangoes is mainly due to the presence of structural polysaccharides such as cellulose, hemicellulose, and protopectin within the fruit tissues. As the fruit ripens, enzymatic breakdown of these structural components occurs, leading to softening of the fruit texture and a gradual decrease in fibre content (Wills *et al*., 1989) [50].

2.3 Carbohydrates and Energy

Ripe Mango contains considerably higher carbohydrate content (16.9 g/100 g) and energy value (74 kcal/100 g) than unripe mango, which contains about 10.1 g carbohydrates and 44 kcal per 100 g. This increase is mainly attributed to the enzymatic conversion of starch into simple sugars such as glucose, fructose, and sucrose during the ripening process, thereby enhancing the sweetness, flavour, and calorific value of the fruit (Yahia, 2011) [51].

2.4 Vitamin C Content

Mango is a valuable source of vitamin C (ascorbic acid), an important natural antioxidant that contributes to human health. The vitamin C content in mango varies depending on factors such as cultivar, stage of maturity, environmental conditions, and post-harvest handling practices. Ascorbic acid plays a significant role in minimizing oxidative stress, enhancing immune response, and protecting the body against cellular damage caused by free radicals (Kaur & Kapoor, 2001) [23].

2.5 Carotenoids and β-Carotene

Ripe Mango contains significantly higher amounts of total carotene (2210 µg/100 g) and β-carotene (1990 µg/100 g) compared to unripe mango. During the ripening process, chlorophyll degradation occurs simultaneously with the synthesis of carotenoids, resulting in the characteristic yellow to orange colour of ripe mango pulp. β-carotene functions as a provitamin A compound and possesses strong antioxidant properties that help protect cells from oxidative damage while also contributing to vision, immune function, and overall health (Ribeiro *et al*., 2007) [37].

2.6 Mineral Composition

Mango is a good source of several essential minerals such as potassium, calcium, sodium, phosphorus, and iron, which are important for various physiological and metabolic functions in the human body. Ripe mango generally contains higher levels of potassium, a mineral that plays a vital role in maintaining electrolyte balance, regulating blood pressure, and supporting cardiovascular health. In contrast, unripe mango possesses comparatively higher amounts of phosphorus and sodium. The mineral composition of mango is influenced by several factors including cultivar, soil nutrient status, irrigation practices, climatic conditions, and the stage of fruit maturity (Nigam *et al*., 2007) [33].

2.7 Functional Importance of Unripe Mango

Unripe mango is extensively used in the preparation of dehydrated powders, pickles, beverages, chutneys, and various traditional food products due to its high acidity, elevated fibre content, and distinctive sour flavour. The comparatively lower sugar content of unripe mango reduces stickiness during processing, while its higher structural integrity makes it more suitable for drying and dehydration operations. These characteristics improve powder recovery, storage stability, and processing efficiency, making unripe mango an ideal raw material for the production of mango powder and other value-added food products (Singh & Sharma, 2018) [43].

Table 1: Nutritional Composition of Ripe and Unripe Mango

Nutrients	Ripe Mango	Unripe Mango
Protein (g)	0.6	0.7
Fat (g)	0.4	0.1
Minerals (g)	0.4	0.4
Fiber (g)	0.7	1.2
Carbohydrate (g)	16.9	10.1
Energy (Kcal)	74	44
Vitamins C (mg)	16	3
Total carotene (mcg)	2,210	90
Beta carotene (mcg)	1,990	-
Potassium (mg)	205	83
Sodium (mg)	26	43
Calcium (mg)	14	10
Iron (mg)	1.3	0.33
Phosphorous (mg)	16	19

(Source: Nigam *et al*., 2007) [33]

3. Preparation of Raw Mango Powder
3.1 Sourcing of Raw Material
Fully matured unripe mango fruits such as Totapuri, Rajapuri, or local Desi cultivars are selected based on their high acidity, pulp recovery, and suitability for dehydration. Fruits obtained from orchards following organic or low-chemical agricultural practices are preferred to minimize pesticide residues and maintain product safety and quality. Mango cultivar significantly influences powder yield, acidity, colour retention, and sensory characteristics of the final product.Studies have reported that Totapuri and Rajapuri mangoes are highly suitable for dehydrated mango products because of their higher pulp content and desirable acidic flavour profile (Hussain *et al*., 2021; Singh and Sharma, 2018) [21, 43].

3.2 Cleaning and Washing
The selected mango fruits are washed thoroughly using potable water to remove adhering dirt, dust particles, latex, microbial contaminants, and pesticide residues from the fruit surface. Proper washing improves microbiological safety and reduces contamination during further processing operations. In some processing systems, sanitizing agents such as potassium metabisulphite (KMS) or chlorinated water are used to reduce enzymatic browning and microbial load.According to food processing studies, washing and sanitization are essential pre-treatment steps that improve the hygienic quality and shelf stability of dehydrated fruit products (Fellows, 2017) [18].

3.3 Peeling and Slicing
After washing, the mangoes are manually or mechanically peeled, and the pulp is sliced into thin uniform slices of approximately 2-4 mm thickness. Uniform slice thickness facilitates efficient heat and mass transfer during drying, resulting in consistent moisture removal and reduced drying time. Smaller slice thickness also enhances drying efficiency and minimizes case hardening.Research indicates that slice thickness significantly affects drying kinetics, colour retention, and final product quality in dried mango products (Doymaz, 2010) [13].

3.4 Drying Process
The prepared mango slices are arranged in a single layer on stainless steel or food-grade perforated trays and dehydrated in a tray dryer or hot air dryer at 55-60°C for approximately 10-12 hours until the moisture content reaches a safe storage level (generally below 10%). Controlled drying temperature is critical to preserve vitamin C, organic acids, flavour compounds, and colour pigments while inhibiting microbial growth and enzymatic activity.Hot air drying at moderate temperatures has been widely reported as an effective method for preserving the physicochemical and sensory properties of raw mango powder (Sogi *et al*., 2015; Mujumdar, 2014) [32, 45].

3.5 Grinding and Powder Formation
The dried mango slices are pulverized using a grinder or pulverizer under low-temperature conditions to obtain a fine powder. Low-temperature grinding minimizes thermal degradation of volatile flavour compounds, carotenoids, and heat-sensitive nutrients. The powder is then sieved to achieve uniform particle size and improve product consistency. Particle size reduction improves dispersibility, solubility, and overall sensory acceptability of fruit powders (Bhandari and Howes, 1999) [8].

3.6 Packaging and Storage
The prepared raw mango powder is packed immediately in moisture-proof and oxygen-barrier packaging materials such as metalized polyester/polyethylene (PET/PE) laminates or kraft paper-lined pouches. Proper packaging protects the powder from moisture absorption, oxidation, light exposure, and flavour loss during storage. The packaged product is stored under cool and dry conditions to maintain shelf life and product stability.Studies on dehydrated fruit powders have shown that barrier packaging materials significantly improve storage stability and reduce quality deterioration caused by moisture uptake and oxidative reactions (Ranganna, 2010) [36].

4. By product utilization
Several million tons of mango wastes are produced annually from factories. Because mango is a seasonal fruit, about 20% of fruits are processed for products such as puree, nectar, leather, pickles and canned slices, among others, which have worldwide popularity (Loelillet, 1994). During the processing peel and mango kernel, which are good source of nutrients, are discarded. The byproducts are valuable source of nutrients and value addition can generate revenues and can address the disposal issues as well.

4.1 Mango peel
During processing of mango, peel a major by- product, contributes about 15-20% of the fruit (Beerh and Raghuramaiah, 1976). As peel is not currently utilized for any commercial purpose, it is discarded as a waste and becoming a source of pollution. Peel has been found to be a good source of phyto-chemicals, such as polyphenols, carotenoids, vitamin E, dietary fibre and vitamin C and it also exhibited good antioxidant properties (Ajila *et al*., 2007; Kim *et al*., 2010) [2, 24].
The total dietary fiber content in macaroni increased from 8.6 to 17.8%. The content of polyphenols increased from 0.46 to 1.80 mg/g and carotenoid content increased from 5 to 84 µg/g of macaroni with 7.5% incorporation of mango peel powder. The macaroni products incorporated with mango peel exhibited improved antioxidant properties. (Larrauri *et al*. 1996) [27] developed technology for jam manufactured from mango peel. Inactivation of polyphenol oxidase was done by immersion of peel in boiling water and followed by extraction of peel soluble compounds at 80oC, and addition of sugar, citric acid and pectin as required. The mixture was then concentrated, cooled and packed. The jam was rated good in sensory test. Effect of some technological parameters on preparation of mango peel dietary fiber was studied (Larrauri *et al*., 1996) [27]. Fresh mango peel was wet milled, washed with water and dried. Results showed that mango peel is a good source of tropical fruit fiber.

4.2 Mango kernel
Mango kernel is a good source of starch and fat. A preliminary study showed that the seed represents from 20% to 60% of the whole fruit weight, depending on the mango variety and the kernel inside the seed, which represents from 45% to 75% of the whole seed (Maisuthisakul and Gordon, 2009) [29]. Following the value of fatty acid composition (12.3 g lipid per 100 g dry seed kernel powder) and phenolic

compounds (mango seed kernel contains total polyphenols, 112 mg per 100 g dry seed kernel powder) present in mango seed kernel. (Soong *et al*, 2004) [47] indicated that mango seed kernel has potent antioxidant activity with relatively high phenolic contents. They observed that that mango seed kernel was also a good source of phytosterols, such as campesterol, bsitosterol, stigmasterol and also contains tocopherols. (Schiber *et al*, 2003) [41] and (NunezSelles, 2005) [34] referred that the antioxidant effect of the mango seed kernel was due to its high content of polyphenols, sesquiterpenoids, phytosterols and microelements like selenium, copper and zinc.

Mango seed kernels have a low content of protein but they contain the most of the essential amino acids, with highest values of leucine, valine and lysine (Kittiphoom, 2012) [25]. (Ashoush and Gadallah,2011) [6] evaluated the effect of mango by products i.e. mango peel and seed kernel powder incorporated in biscuit to check its total phenolic content and antioxidant activity effect in prepared biscuit. Mango kernel fat alone or when blended with other nut fats like almond, palm stearin, can act as cocoa butter replacer (Moharram and Moustafa, 1982; Solís-Fuentes and Durán-de-Bazúa, 2004; Jahurul *et al*. 2013; 2014).

The cocoa butter replacer has good triglyceride content and thermal properties. (Moharram and Moustafa, 1982) extracted fat from mango seed kernel (Mangifera indica) and observed that triglycerides, fatty acids and phospholipids were comparable with those of cotton seed oil, cocoa butter. They also incorporated mango seed kernel oil in butterscotch toffee and found that mango kernel oil and cocoa butter were almost identical in several of their triglycerides, fatty acids and effects on taste, odour and texture of the toffee. (Arogba, 2001) [5] prepared biscuit from equal amount of wheat and mango seed kernel powder.

4.3 Pectin from solid (mango peel and kernel) waste

A study was carried out to establish optimum extraction conditions for the extraction of pectin from mango solid waste. Highest pectin yield was obtained at pH-3, bleaching with alcohol and extraction time of 60 minutes (Pedroza *et al*., 1994) (Tandon and Kalra,1991) extracted pectin from dry peel and kernel of immature and ripe Dashehari Mangoes using 0.05N NaOH, 0.05NHCl and 0.3% sodium hexameta-phosphate (SHMP). Maximum yield of 12.79% pectin was obtained in ripe mango peel from SHMP extraction. The kernel contained very little amount of pectin. The water-soluble pectin was more in peel of ripe fruit while alkali soluble fraction was more in peel of immature fruit.

4.4 Production of vinegar from mango waste

The potential of using mango (var. Totapuri) peels and stones for the production of vinegar was investigated (Ethiraj and Suresh, 1992) [14]. Alcoholic fermentation of these waste products was carried out by two methods. Peels or stone were mixed with (cold or hot water) (50%w/w) and saccharin. The extracts of peels or stones were treated with 50ppm SO2 inoculated with Saccharomyces cerevisiae var. ellipsoideus and fermented (24+4 oC, 72hrs). The base wine from peel and stone washings contained 2.5 and 3% alcohol, respectively. The alcohol content was increased to the desired level for acitification (5%) by alcohol fortification or secondary fermentation (addition of 4% cane sugar and 0.15 yeast extract). Acetification by batch type fermentation using Acetobacter rancans required 3½ days for completion and produced good quality vinegar (4.5-5% acetic acid) characterized by mild mango flavour.

5. Conclusion

Raw mango powder is an important value-added product with significant nutritional, functional, and commercial potential in the food processing industry. The high acidity, fibre content, and low sugar concentration of unripe mango make it highly suitable for dehydration and powder production. Drying technologies play a crucial role in determining product quality, nutrient retention, and storage stability, while advanced drying methods offer improved preservation of flavour, colour, and bioactive compounds. However, challenges such as stickiness, hygroscopicity, and caking still affect powder quality and require further technological improvements. Additionally, mango processing by-products such as peel and kernel can be effectively utilized as valuable sources of antioxidants, dietary fibre, pectin, and edible fats for functional food applications. Therefore, further research on optimized processing techniques, packaging, and by-product valorization can enhance the industrial applicability, shelf stability, and sustainability of raw mango powder production.

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