Mango Kernel as a Non-conventional Food Source to Address Food Security Challenges

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Abstract

Mango known as the king of fruits has a tremendous demand in food processing industries. The processing and consumption of mango fruit contributes a significant amount of nutritionally valuable by-products. These secondary products are normally left unutilized causing environmental contamination. The principal by-product of mango processing is mango kernel which constitutes almost 20 % of the whole fruit depending upon the variety and the stage of maturity. This kernel is the potential source of nutrients including complex carbohydrates, fat, protein, polyphenols, mangiferin, and other bioactive compounds if properly processed. Unconventional food sources like mango kernel can play a pivotal role in fulfilling the nutritional needs of the human body in the current era where people are struggling for physical and economic access to food. This book chapter provides insights into the nutritional composition, processing, and potential applications of mango kernel in the bakery, edible oil, and confectionery industries.

Keywords: Mango kernel flour, Food poverty, Unconventional food sources, Mango kernel applications, Cocoa butter substitute

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Introduction

Food is essential for the sustenance of human beings and their ecosystem. Food can be consumed in its natural state or as processed products with added value. The growing population necessitates increased food production to meet their caloric needs. (Gupta & Mishra, 2021). To ensure the health and well-being of the population, it is crucial to produce food on a sustainable basis. The same ideas are motivating international organizations for the exploration of unconventional food sources to feed the masses. Food security is one of the most pressing challenges in the world. The Food and Agriculture Organization (FAO) mentioned that about 10% of the world's population, i.e., nearly 800 million people, are still suffering from hunger and malnutrition (FAO, 2024).

Despite major advances in agricultural productivity, many regions around the world are confronting food insecurity as a result of poverty, climate change, and inadequate distribution networks. Furthermore, the provision of malnourished diets is exacerbating public health concerns in the form of chronic non-communicable diseases such as obesity, diabetes, cardiovascular diseases, etc., especially in low and middle-income nations. In addition, the world population is projected to exceed 9.7 billion by 2050, creating additional stress on already overburdened food systems. This rise in population, along with the growing threat of climate change, enhances the risk of food poverty (Saleem et al., 2024).

Food poverty is a major global issue, impacting millions of people who do not have access to sufficient nutritious food. Therefore, exploring untapped energy sources for the human body, mainly focusing the fruit and vegetable processing waste is needed to compete with the rising needs of the ever-increasing human population (Kringel et al., 2020). The proclaimed nutritional composition of various waste products from the food processing sectors makes them desirable as unconventional food sources. Normally, this waste after being entirely broken down by microbes is causes pollution and of other environmental problems such as an increase in the carbon and methane footprints (Utama et al., 2020). To reduce food insecurity, it is necessary to valorize principal and by-products of agricultural production into affordable, and high-quality raw materials for the production of valuable food products and the sustainability of the global population in the future (Kumari et al., 2020).

1. Mango Fruit and its by-products

With an annual production of about 54 million tons worldwide, mango is the second most important fruit in the world. (FAOSTAT, 2022). The three layers that constitute a mango fruit include: the peel (epicarp), pulp (mesocarp), and seed (exocarp) Figure 1. It is high in fiber and vitamins, particularly A and C, and low in calories. Minerals including calcium, iron, and zinc are also present. Some phytochemicals, like gallotannins and mangiferin, are unique to mangoes. A wide variety of value-added products, including nectar, fruit drink, jam, chutney, leather, and puree are typically made from the pulp of mango fruits. Seeds and peels are thrown away as waste in significant quantities after fruit pulp is consumed in homes or businesses (Lebaka et al., 2021).

Mango fruit contributes approximately 210,000 metric tons of waste annually worldwide, with a fruit-to-waste generation ratio of 25 to

40%. Processing industries fail to utilize several million tons of mango waste because of a lack of accurate information, which leads to social, environmental, and management issues due to a lack of information to convert mango processing by-products into bio-available value added products for commercial use. The estimates showed that the industrial and household consumption of mango produces different by-products after peeling and pitting, almost 25 million tons per year (Mwaurah et al., 2020).

Since mango by-products are organic, they disintegrate quickly serving as a breeding ground for insects and raising the amount of chemical and biological oxygen demand, which is why improper disposal of them is contributing to environmental pollution (Oliver-Simancas et al., 2021). Multiple studies have shown that mango by-products are rich in a variety of health-nourishing bioactive substances, such as dietary fibers, phenolic compounds, carotenoids, etc., supporting the nutraceutical and health benefits of mango processing waste (García-Mahecha et al., 2023; Ahmad et al., 2022; Marsiglia-Fuentes et al., 2023). Repurposing bioactive compounds from mango processing by-products and utilizing them as nonconventional food sources could be one of the novel strategies to address the problem of food insecurity (Gupta et al., 2022).

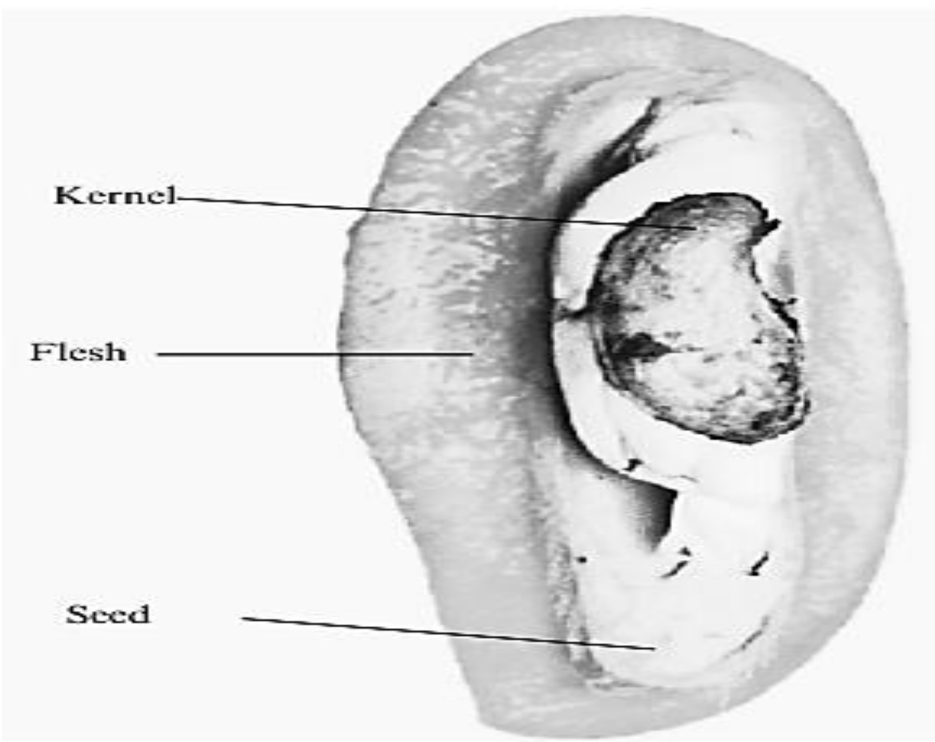

Fig. 1: Cross-sectional view of mango fruit illustrating mango seed and mango kernel

2. Mango Kernel: A Nonconventional Food Source

i. Nutritional composition

Mango kernel has long been considered a valuable component of the human diet owing to its high nutritional value. The nutritional value of mango kernel is 20-50 times higher than an equivalent amount of mango pulp (Patel & Kheni, 2018). The nutritional composition of mango seed kernels as reported by different studies is shown in the table.1. Different factors including environmental, genetic, and varietal differences affect the proximate composition. The ranges of different nutrients in mango kernel are 70-78% carbohydrate, 9-15% crude fat, 6-10% crude protein 1-3% ash 0.5-4% crude fiber, and 0.1–8.6 g GAE/100 g polyphenols on a dry weight basis. The mineral matter of the kernel included calcium, sodium, magnesium, potassium, and phosphorus (Tsiaka et al., 2017). Other microelements including zinc, copper, and selenium are also present in kernels (Kittiphoom & Sutasinee, 2013). Based on the nutritional composition, it is important to utilize mango seed kernel in food. It has the potential to overcome the issue of food insecurity in developing countries because it has substantial amounts of health-supporting bioactive compounds like complex carbohydrates, phenolic compounds, important fatty acids, and vitamins (Mas'ud et al., 2020).

Table 1: Nutritional composition of Mango kernel

Mango kernel	Carbohydrate	Protein	Fat	Ash	Crude fiber	Moisture	Reference
	70.12	10.06	14.80	2.62	2.40	-	Lahutiya & Yadav, 2023
	78.03	6.13	9.53	2.53	3.77	2.97	Ojha et al., 2019
	70.0	10.0	15.0	2.0	2.0	-	Patel & Kheni, 2018
	69.77	7.53	11.45	1.0	2.20	7.05	Yatnatti et al., 2014
	76.81	6.80	10.50	2.68	2.0	9.24	Kaur & Brar, 2017

ii. Kernel Carbohydrate

The macronutrients that provide the body with its principal energy source are carbohydrates, mostly starches. The production of polysaccharide derivatives of various starches for a range of uses in various industries has been the focus of intense global efforts. Plant-based starch is mostly processed into products meant for human use, although it can also be used to make fermented drinks, ethyl alcohol, and sweeteners, or to produce animal feed (Yazid et al., 2018). The starch extracted from the mango kernel exhibited a variety of functional properties. It had an average amylose and amylopectin concentrations of 14.75% and 84.25%, respectively. At 85 °C, the swelling power (g/g) water binding capacity (%) and solubility (%) were 19.40, 75, and 0.135 respectively. The onset, peak, and conclusive temperatures for gelatinization were found to be 62, 66, and 71 degrees Celsius respectively. Scanning electron microscopy (SEM) showed starch granules possess oval shape (Shahrim et al., 2018). Mango kernel starch is suitable for a variety of food applications because it exhibits high viscosity (706BU) and good low temperature stability (de Souza et al., 2021).

In addition to higher peak viscosity and pasting temperature mango kernel starch has a greater gelatinization temperature (Tg) and crystallinity (Saeaurng & Kuakpetoon, 2018). Furthermore, it has high crystallinity and a low gel-forming temperature and oil absorption capacity (Ai & Jane, 2024). Gelatinized mango kernel starch and glycerol/sorbitol were combined in a 1:1 ratio to develop a coating mixture for tomatoes. When stored at 20 °C for up to 20 days, the coated fruits exhibited a delayed ripening process (Nawab et al., 2022). In another study, the effect of edible coating developed from mango kernel starch and glucose was examined on the shelf stability of mango (Palmer variety) over 12 days of storage at 24 °C and 87% relative humidity. It was found that mango kernel starch granules can minimize the rate of respiration and weight loss percentage thereby preserving the fruit quality when applied as the edible coating (Patiño-Rodríguez et al., 2020).

The quality preservation potential of mango kernel starch was assessed in another study by incorporating it into the soup mix. In this study, maize starch was replaced with 25, 50, and 75 percent of the mango kernel starch. After two months, the results of a 50% substitution were found to be similar to those of a 100% corn starch-based soup mix. Reliable results were obtained from sensory scores, and the microbial count was within a safer range. In soup mixes, it was found that the starch from mango kernels may replace up to 50% of the maize starch without causing noticeable changes over a two-month shelf life (Yatnatti & Vijayalakshmi, 2018). Hence, mango kernel starch can be employed as an alternative to commercially available starches in food applications.

iii. Kernel Protein

Studies indicate that depending on the cultivar, the dry weight of proteins in mango kernels can vary from 6% to 13% (Diarra, 2014). Kernel protein contains essential amino acids, including leucine, valine, isoleucine, and lysine i.e., 6.9, 5.8, 4.4, and 4.3g per 100 g of the protein dry weight. Threonine, phenylalanine, tyrosine, valine, isoleucine, and methionine are other amino acids in substantial amounts (Abdalla et al., 2007; Fowomola, 2010). Protein quality and essential amino acid index of mango kernel were high, indicating that the quality of protein is high. The bioavailability of mango kernel protein is also greater than that of egg protein as reported in the study of Abdalla et al., (2007).

The quantity and type of amino acids are other important parameters in determining the protein quality. Abdelaziz (2018) revealed that there are sixteen different amino acids in mango kernel. The major amino acids that makeup almost 48% of the mango kernel protein include glutamic acid, alanine, leucine, aspartic acid, arginine, phenylalanine, lysine, tyrosine, and isoleucine. Furthermore, methionine, proline, valine, threonine, histidine, glycine, and serine were also detected in comparatively lower amounts.

The protein percentage of dried mango kernel varies from 6 to 13%, which is comparable to the protein percentage of maize. The replacement of maize with boiled kernel powder at the rate of 50% in both starter and finisher diets of broiler can reduce feed cost and had not adversely affect the broiler growth (Diarra, 2014). It also presented an upright profile of essential amino acids mainly rich in methionine and lysine. The combined action of autoclaving and soaking improved the bioavailability and tannin reduction of kernel protein. The bioavailability of kernel protein was comparable to egg protein (Legesse & Emire, 2012).

iv. Kernel Oil

The fat percentage in the kernel varies from 3.7 to 13.7% depending upon the region and cultivar. As estimated from the total global production of mango almost 0.03–0.43 million tons of fat could be produced if kernels are collected properly (Jahurul et al., 2015). The chemical composition of kernel oil as studied by Fahimdanesh and Bahrami (2013) was melting point (30 °C), iodine value (55), unsaturated (42–44 %), and saturated fatty acids (52–56 %). The major fatty acid in kernel oil was oleic acid (45%) followed by stearic acid as studied by Soong et al. (2004). Acid value, peroxide value, and iodine value in milli equivalent of oxygen per kg of oil were 27.59, 0.26, and 55 while the saponification value was 206 (Kittiphoom & Sutasinee, 2013).

In another study kernel oil was extracted from six different mango varieties of Pakistan including ratool, fajri, dasehri, laal badshah, white chaunsa, sindhri, and langra. The yield of oil among different varieties varied from 6.33 to 9.88%. Physicochemical parameters were saponification value (143−207 mg KOH/g) refractive index (1.43−1.457) iodine value (28−36 g/100 g) peroxide value (5.5−2.0 meq/kg) acid value (1.00−7.7%) free fatty acids (0.5− 3.9 mg/g) and unsaponifiable matter (1.2−3.3%). The fatty acid profile revealed that the percentages of unsaturated and saturated fatty acids were 47.140−58.08% and 41.92−52.86% respectively. The oleic, stearic, linoleic, and palmitic acids were prominent with percentages of 25.69−48.57, 24.71−38.53, 7.72−16.47, and 10.00−13.26 (Zahoor et al., 2023).

The study conducted to evaluate the allergenic and toxic effect of mango kernel fat indicated that the rats fed with a balanced diet containing 10% of the kernel fat had no adverse effect on serum lipid and cholesterol levels. The effect of refining processes studied on kernel oil quality and melting point indicated that the free fatty acid level was 0.09% after refining and no change was observed in melting point (Yousaf et al., 2024). Moreover, most of the antinutrients are also removed with the unsaponifiable matter during refining. The refined fat can be fractionated into various fractions of having comparable properties to commercial value-added fats like cocoa butter and palm oil fractions (Lieb et al., 2019).

v. Bioactive Components

Mango kernel possesses a diverse profile in terms of phenolics and bio actives including mangiferin, gallic and ellagic acid, alkyl-resorcinol, gallotannins, and benzophenone derivatives with high antioxidative, nutraceutical, and pharmaceutical potential. Mangiferin is a special polyphenol that has a radical scavenging ability comparable to natural antioxidants such as vitamin C and E. It can combat against several degenerative diseases therefore referred to as a super antioxidant (Ahmad et al., 2022). Another study reported that the bioactive profile of mango kernel includes coumaric, caffeic, ferulic, and protocatechuic acids. The glycosides and flavonoids were also reported as quercetin-3-galactoside, quercetin-3-glucoside, quercetin-3-arabinoside, quercetin-aglycon, catechin, anthocyanins, kaempferol, and rhamnetin (Choudhary et al., 2023). Fruit variety and extraction technique determine the total phenolic compounds present in mango seed kernels, generally varies from 18.19 to 200.35 mg GAE per gram of kernel dry weight. The use of high temperatures in extraction denatures the chemicals, producing extracts with little antioxidant activity. Similarly, drying as a preprocessing step impacts the finished product's antioxidant capacity. According to the ABTS assay measurement of radical scavenging capacity, lyophilization produces a 12% antioxidant-rich extract, making it a superior drying method over oven drying (Dorta et al., 2012).

vi. Anti-nutritional Compounds

Trypsin inhibitors, hydrogen cyanide, and phytic acid levels are generally low and within the safe concentration range (<20 mg/100 g) in terms of their anti-nutritional effects. In addition to this, the dry mango kernel contains around 56.5 g/kg of tannins. Inhibiting the activity of specific enzymes in the human body, tannins bind to proteins and minerals. However, there are different techniques reported on reducing the tannin content in the kernel. Soaking, boiling, autoclaving, and acid or alkali treatment have been reported to remove tannins, trypsin inhibitors, and hydrogen cyanide (Uzombah et al., 2019; Dakare et al., 2012).

It was observed that soaking of mango kernel powder before further use significantly reduced the tannin content (Uzombah et al., 2019). In another study, Abdullahi (2012) investigated the effect of processing on the reduction of antinutritional factors in mango kernel starch and found that boiling in water was more efficient in reducing phytate and oxalate while soaking efficiently reduced hydrogen cyanide. Maximum tannin reduction and enhancement of kernel proteins were obtained by the combined action of soaking and autoclaving (Legesse & Emire, 2012). The time and temperature combination should be optimum to preserve the volatile bioactive compounds of the kernel. Das et al., (2019) recommended that the drying temperature should be less than 65 °C and soaking time should not be more than 24hr, to preserve the nutrients and to lessen the antinutrients.

3. Food Applications

i. Flour

The mango seed consists of an endocarp that encloses the kernel (Figure 2). The mango seed kernel comprises 45–85% of the seed and about 20% of the entire fruit. The kernel flour obtained from the decorticated mango seed can be utilized in bakery products for the supplementation of wheat flour. The particle size of the powder obtained after the grinding of kernels impacts the processing of flour into bakery products. Therefore, the kernel should be sliced (0.5 cm thickness) to facilitate the grinding operation (Lakshmi et al., 2016). The processing parameters including soaking, drying, and boiling, that are generally employed during milling, are the main indicators of the nutritional quality of the flour. The major proximate components like starch, protein, and fat are significant affected during drying and soaking pretreatments, while the least effected components are fiber and ash (Zikri et al., 2022; Uzombah et al., 2018).

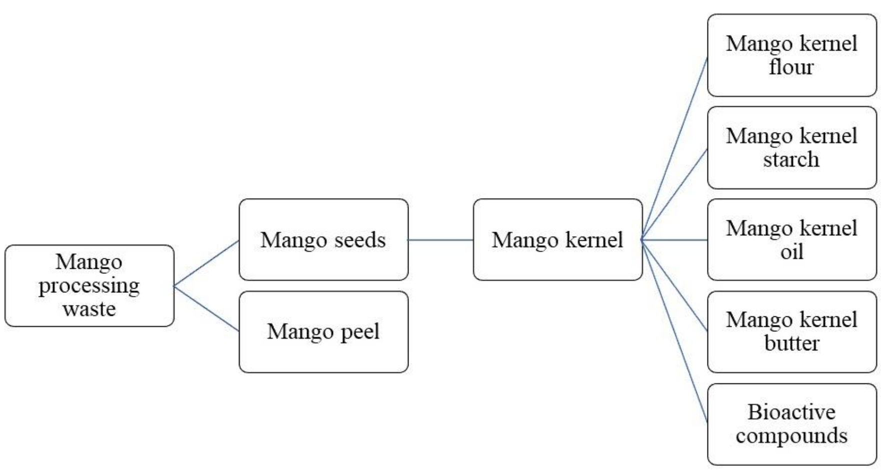

Fig. 2: Potential food applications of mango kernel

Composite flours with enhanced nutritional profile can be developed using mango seed kernel flour in partial replacement of wheat flour for a variety of food applications and with a focus on nutritional superiority. It was revealed that the recovery percentage of flour from mango kernel was 80% with a maximum particle size of 60 mesh. The obtained flour had a considerable amount of protein, fat, and calories, i.e., 7.53g, 11.45 g, and 421 kcal per 100 gm respectively and a substantial amount of calcium, magnesium, and potassium i.e., 170 mg, 210 mg, and 368 mg in 100 grams respectively (Yatnatti et al., 2014).

The nutritional composition of flour as further studied by Das et al., (2019) includes carbohydrate 72.07%, protein 8.03%, moisture 7.58%, ash 2.16%, fat 10.16%, crude fiber 1.16% and comparatively higher energy value (4.12 kcal/g) than wheat flour (3.54 kcal/ g). The flour also showed a higher water absorption and bulk density, while lower oil absorption and swelling power than an equal amount of wheat flour. Moreover, kernel flour also possesses therapeutic and functional properties due to the presence of ascorbic acid and polyphenols as studied by Uzombah et al. (2019). The replacement of wheat flour with 10 -15 % of mango kernel flour results in a higher percentage of fat, protein, and ash as well as better sensory properties of the ultimate product (Gumte et al., 2018).

ii. Bakery Products

The bakery products can be developed with enhanced nutritional profiles using multigrain and composite flour and is also a challenging need of the bakery industry. The use of mango kernel flour can be nutritionally and economically beneficial to baking industry for the development of nutrient-dense products and for mitigating food security (Chaudhary & Chhabra, 2023). The chemical and functional composition including phenolics, flavonoids, amylose, and amylopectin content, and pasting properties of regular wheat flour can be enhanced by the development of its composites with mango kernel flour (Irondi et al., 2017).

The bakery products developed with margarine containing mango kernel oil revealed better textual properties than those developed using commercial margarine. The muffin cakes developed by using this margarine in 25-100% replacement of commercial margarine exhibited a better fatty acid profile and sensory properties particularly at a 50% level of replacement (Jeyarani et al., 2015). The potential of mango kernel oil to replace normal shortenings used in bakery products was studied by Saddique et al. (2014). It was revealed from the study that the lipid fraction of mango kernel was liquified at 26.2 °C. The replacement of fat at the level of 15 - 20% was acceptable by the sensory panelist.

The cakes developed by replacing some percentage, up to 40%, of wheat flour with mango kernel flour increased the energy value (Kcal) by 3.06%. The sensory score indicated that the cakes containing 20% kernel flour had the highest overall acceptability. The data from the storage study revealed that these cakes had better shelf stability for up to 10 days without added preservatives than the control (Das et al., 2019). In another study, muffins developed using composite flour containing 10-40% mango kernel flour in replacement of refined wheat flour. It was revealed from the results that the organoleptically acceptable and nutritionally improved muffins were developed with composites containing 30% mango kernel flour (Thenabadu & Seneviratne, 2022).

The biscuits developed consuming composite flour containing up to 40% kernel flour with all-purpose wheat flour revealed better antioxidant and organoleptic properties. The energy value in kcal, nutritional and mineral profile including calcium, magnesium, and iron were increased significantly (Kaur & Brar, 2017). In another study, biscuits developed with a 15% replacement of wheat flour with kernel flour presented higher dietary fiber and phenolic content. Moreover, sensory properties of biscuits were also good having slight mango taste and storage stability of 30 days at room temperature (Aslam et al., 2014). In a separate study, the biscuits developed with 10 - 40% incorporation of kernel flour in conventional recipe revealed better nutrition with high consumer acceptability (Gumte et al., 2018).

Some antinutritional compounds including cyanic acids and trypsin inhibitors can limited the utilization of kernel flour in bakery products. Different pretreatments could be employed to remove these phytochemicals like Hafez et al. (2012) suggested the use of 1% salt (NaCl) solution as a pre-treatment of kernel powder before utilization in bakery formulations. This treatment also leaches the small amounts of some beneficial nutrients like reduces the total protein and carbohydrate content. Despite this leaching, the incorporation of treated powder in biscuit recipe improved the overall nutritional profile and storage stability of the developed biscuits. Furthermore, a significant weight gain was recorded in rats fed on these biscuits.

Cocoa Butter Substitute

The fat present in mango kernel has a significant substitution potential to cocoa butter in confectionery items. Since its fatty acids and their corresponding triglyceride composition and melting behavior of kernel fat exhibit closed resemblance to cocoa butter as reviewed by Jia et al. (2019). Furthermore, only six fats, based on the physical and chemical properties, are recommended by the European Union Directive (2000/36/EC) for use in confectioneries to substitute cocoa butter, mango kernel fat is one of them. The processing steps include in the extraction of mango kernel fat also suggest it a cost-effective and environment friendly alternate to cocoa butter. The characteristics exhibited by mango kernel fat can be enhanced further by mixing it with other oils (Kaur et al., 2023). In another separate study Kaur et al. (2022) evaluated that mango kernel fat could substitute up to 80 percent of cocoa butter in dark chocolate preparation. The properties of a blend containing mango kernel fat and rice bran oil was evaluated to substitute cocoa butter in chocolate. It was revealed from the results that a 5 % replacement of cocoa butter with this blend give satisfactory results regarding physical and sensory attributes (Mokbul et al., 2023). Similarly, the mixture of kernel oil prepared with palm oil in an 80:20 (w/w) ratio showed fatty acid proportions including oleic, palmitic, and stearic acids comparable to those present in cocoa butter (Sultana & Ashraf, 2019).

Conclusion

Currently, strategies regarding food processing and value addition are being made considering the sustainable development goals of zero waste and hunger eradication. The biological potential of by-products of food processing industries with high nutritional content and functional values such as mango seed kernel should be harnessed for use in the normal human diet. The production of mango kernel flour requires minimum processing arrangements to meet the nutritional needs of society. The bioactive components in mango kernels have the potential to be a natural source of antioxidants. Moreover, mango kernel can be used as a food element to assist in alleviating oil and protein calorific needs to address food security and malnutrition. Therefore, there is a need to raise awareness in terms of the nutritional value of these bioactive components incorporated into diets. Further research is also crucial to improve the quality and acceptability of mango kernel products in addition to clinical studies needed to support the plausible health benefits of mango kernel products.

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