

## Review

# Mango Fruit Processing: Options for Small-Scale Processors in Developing Countries

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**Abstract:** Postharvest losses of mango fruit in a number of developing countries in Africa and Asia have been estimated to be as high as over 50%, especially during the main harvest season. Micro, small, and medium scale food processing enterprises play an important economic role in developing economies in processing of a diversity of healthy food products as a sustainable way to reduce postharvest losses and food waste, extend shelf life of food, boost food security, and contribute to national gross domestic product. Processing of mango fruit into the diverse shelf-stable products makes the seasonal fruit conveniently available to consumers all year round. Over the years, research and food product development have contributed substantially to a number of unique and diverse processed mango products with specific qualities and nutritional attributes that are in demand by a wide array of consumers. These mango products are derived from appropriate food processing and value-addition technologies that transform fresh mango into shelf-stable products with ideal organoleptic, nutritional, and other quality attributes. Some of the common processed products from mango fruit include pulp (puree), juice concentrate, ready-to-drink juice, nectar, wine, jams, jellies, pickles, smoothies, chutney, canned slices, chips, leathers, and powder. Minimum processing of mango fruit as fresh-cut product has also gained importance among health-conscious consumers. Apart from the primary products from mango fruit, mango pulp or powder can be used to enrich or flavor secondary products such as yoghurt, ice cream, beverages, and soft drinks. Byproducts of mango processing, such as the peel and kernel, have been shown to be rich in bioactive compounds including carotenoids, polyphenols, and dietary fibers. These byproducts of mango processing can be used in food fortification and manufacture of animal feeds, thereby gaining greater value from the fruit while reducing wastage. This review focuses on the current trends in processing and value addition of mango applicable to small-scale processors in developing countries.

**Keywords:** postharvest loss; shelf stable; nutrition; bioactive; byproducts



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## 1. Introduction

Food processing is one of the strategic sectors where developing countries can use their natural base in agriculture to reach the next level of economic development [1]. Food processing in developing countries was, until one or two decades ago, dominated by multinational companies headquartered in advanced economies. However, economic liberalization increased the competitiveness of the structure of the food industry, thereby contributing to more rapid food product and process innovations [2]. In developing countries, population increase, rapid urbanization, rise of the middle class and changing food habits led to a gradual increase in demand for processed, nutritious and healthy food products. This has in turn contributed to the rise of micro, small, and medium scale food processing enterprises (MSMFPE) that process a diversity of healthy and nutritious food products as a sustainable way to reduce postharvest losses and food waste, extend shelf life of food, boost food security, and contribute to national employment and national

gross domestic product. The small-scale nature of these food processing enterprises and low level of bureaucracy enables them to rapidly make strategic decisions to respond to demand or change in the local market. These MSMSFPE are however plagued with a number of both upstream and downstream supply chain challenges such as; poor road network especially in rural areas which increase the cost of sourcing of raw materials or distribution of processed products; in a number of developing countries, the food processing sector is still informal thus contributing to inefficiencies in the food value chain that lead to high retail cost of processed products; duplicity and overlaps in laws and regulations governing the food processing sector; confinement of the market of processed food products in urban areas; high cost of food processing equipment; high cost of energy, credit and taxation. However, these enterprises hold potential to economic development in the developing countries if made more competitive, through increased government initiatives, interventions and conducive regulatory and taxation policies, adoption of novel food products and processing innovations, with more stringent quality and safety management systems. Only then will they be able to ward off the challenge of competitive imports from more advanced economies.

One of the most important fruits with a greater potential for food processing in some of the developing countries is the mango. Mango fruit is the second most traded tropical fruit globally and ranks seventh in terms of production [3]. Mango, “also referred to as the ‘king of fruits’”, is a major fruit of the tropics and subtropics. Although the fruit is mainly consumed in its fresh state, mango can be processed into many nutritious and shelf-stable products. Mango production postharvest losses in developing countries such as Kenya have been estimated to be as high as over 50%, especially during the main harvest season [4]. Other countries such as Rwanda, India, Benin, and Ghana reported mango postharvest losses in the range of 30–80% during harvesting, packing, and distribution in retail and wholesale markets [5]. Processing of mango fruit into diverse shelf-stable products makes the seasonal fruit conveniently available to consumers all year round. Some of the common processed products from mango fruit are derived from the pulp. Apart from the primary products from mango pulp, derivatives of mango pulp can be used to enrich or flavor secondary products such as yoghurt, ice cream, beverages, and soft drinks. Byproducts of mango processing such as the peel and kernel have been shown to be rich in bioactive compounds including carotenoids, polyphenols, and dietary fibers. The byproducts of mango processing can be used in food fortification and manufacture of feeds, thereby gaining greater value from the fruit while reducing wastage. Although mango is amenable to processing into all these products, smallholder farmers and processors in developing countries have not fully exploited this potential. Over the years, research and food product development have contributed substantially to a number of unique and diverse processed mango products with specific qualities and nutritional attributes that are in demand by a wide array of consumers. These mango products are derived from appropriate food processing and value-addition technologies that transform fresh mango into shelf-stable products with ideal organoleptic, nutritional, and other quality attributes. The status of processing technologies and products from mango has been reviewed in the recent past by DeeptiSalvi and Karwe [6], Evans et al. [7], and Siddiq et al. [8]. This review focuses on the current trends in processing and value addition of mango applicable to micro, small and medium food processing enterprises in developing countries.

The mango products of interest described in this mini review include the following as illustrated in Figure 1.

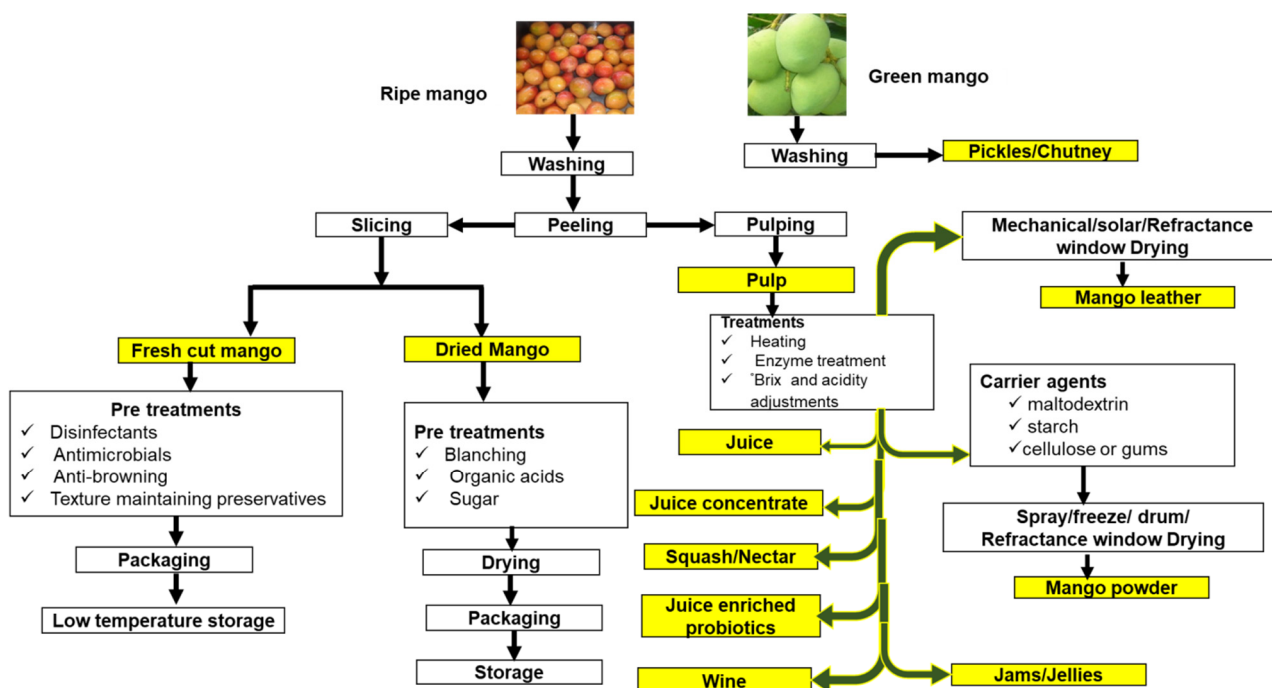


Figure 1. Processing of different products derived from mango. (Modified from [8,9]).

## 2. Fresh-Cut Mango (FCM)

FCM is among the minimally processed fruits and vegetables with increased market demand within ready-to-eat fresh fruit products [10,11]. In general, the factors that are fundamental to the quality of FCM include quality of intact mango, mango cultivar, preharvest agronomic practices, harvest maturity, postharvest handling procedures, interval between harvest and processing of the FCM, and the preparation methods, i.e., sharp cutting tools, size and surface area of the slices, washing and removal of surface moisture [12,13]. Nevertheless, peeling and cutting operations involved in processing FCM eliminate the protective pericarp and stimulate the physiological and biochemical activities that predispose the product to dehydration, accelerated tissue softening, and surface browning. Hence, there is a much higher rate of deterioration compared to intact fruit. As a consequence, even with preservation treatments to extend their shelf life, FCM have a consumption window of just a few days. To assure fresh-like quality and extend the shelf life of FCM, currently a combination of treatments and preservation methods are utilized. The dip pretreatments incorporate disinfectants, antimicrobials, antibrowning, and texture-maintaining preservatives [8,14].

The most common disinfectants with antimicrobial activity for FCM are sodium hypochlorite (NaOCl), and calcium hypochlorite (CaCl<sub>2</sub>O<sub>2</sub>). The recommended dose of chlorine ranges between 50 and 200 ppm, pH 6.0–7.5, with a contact time of 2–5 min [10,15]. Some other available alternative sanitizers that can be used for FCM and that are available in the market include aqueous chlorine dioxide (<3 mg L<sup>-1</sup> in water) and hydrogen peroxide (an effective sanitizer especially against *Salmonella* spp., *E. coli* O157:H7, *B. subtilis*, and other foodborne microbes at a dose of <0.3 mg L<sup>-1</sup>, (in vapor form, otherwise it can be phytotoxic). Other sanitizers include calcium solutions (calcium chloride, calcium carbonate and calcium citrate, calcium lactate, calcium phosphate, calcium propionate, and calcium gluconate at a dose of 0.5% to 3% for 1–5 min). In addition, organic acids (0.5–1% ascorbic combined with 1–2% citric acids) are useful alternatives to sulfites in preventing browning and discoloration of cut slices. Acetic acid (vinegar) at a dose of 4% is also an effective antimicrobial [10,16]. The combination of these dipping treatments with edible or polysaccharide-based coating such as chitosan or alginate has also been demonstrated to be useful in extending the shelf life of fresh-cut products [9,17,18].

### 3. Pulp

Depending on the cultivar, mango pulp constitutes about 40–60% of the total fresh fruit weight, and is the main consumable part of the fruit due to the presence of nutritional and functional compounds [19]. The nutritional compounds and bioactive composition of mango are factors of the cultivar, the agroecological condition of the region, and the maturity of the fruit [20–23]. Sucrose, fructose, and glucose (in decreasing order of their concentration) comprise the principal carbohydrates present in mature and ripe mango. The carbohydrates content of pulp averages about 15 g/100 g, total dietary fiber (pectins, hemicellulose, and celluloses) averages 1.6 g/100 g while the protein content is about 0.8 g/100 g. The pulp also contains important micronutrients, vitamins, and bioactive compounds. The vitamin C of mango pulp ranges between 98 mg to 18 g/kg depending on variety and stage of maturity [23]. The nutritional quality of mangoes is to a great extent contributed by carotenoids, particularly  $\beta$ -carotene at about 4.138 mg/100 g [24]. The Tommy Atkins variety has been reported to contain 0.64 mg  $\beta$ -carotene, 0.009 mg  $\alpha$ -carotene, 0.01 mg  $\beta$ -cryptoxanthin and lutein, and 0.023 mg zeaxanthin per 100 g [22,25]. This indicates that there is variation of carotenoids naturally among mangoes as a result of climatic effects, variety differences, stage of maturity at harvesting period, and storage. The ripe mango pulp contains all the B complex vitamins except biotin, ranging from 1.5 to 2.5 mg/100 g of fresh fruit pulp [23,26]. Mango pulp is a good source of many micro- and macro-minerals such as calcium, sodium, copper, iron, phosphorus, manganese, magnesium, zinc, boron (0.6–10.6 mg/kg), and selenium. The pulp is also rich in organic acids including citric acid, malic acid, oxalic acid, succinic acid, ascorbic acid, and tartaric acid, and bioactive compounds such as phenolic acids, sterols, and alkaloids [27,28].

The ability of the mango pulp to retain a wide range of nutrients and bioactive compounds is what makes it an ideal base material in the processing and value addition of various products) [8,22]. The pulp is rich in fiber due to the presence of fruit membrane and hence is more advantageous in comparison to juice concentrate in the processing of products. For storage purposes, the pulp is generally standardized to 14–18°Brix and 4–6% acidity by the use of either sugar syrup or citric acid, respectively. The sugar-standardized pulp is then pasteurized at 85 °C, filled when hot into bulk containers and sealed or heated at 100 °C for 20 min, cooled, packaged into bulk containers, and stored at room temperature (~25 °C). Addition of ascorbic acid, sorbic acid, sodium metabisulfite, and sodium benzoate into mango pulp helps in color, flavor, and carotene retention, resulting in a much longer shelf life. Both sodium metabisulfite and sodium benzoate have antimicrobial effects, but metabisulfite is more effective. However, minimal negative effects have been reported on the sensory characteristics of juices prepared from mango pulp preserved by metabisulfite and benzoate.

Mango pulp serves as the base for the processing of a variety of mango products including the following.

#### 3.1. Mango Juice

Mango pulp can be mixed with a specific ratio of water to produce mango juice of a final TSS ranging between 12 and 15% of °Brix and 0.4 and 0.5% acidity [8,29,30]. The mango juice can be used as a single strength juice or blended with other fruit juices as juice blends or incorporated in fruit smoothies/shakes.

#### 3.2. Mango Juice Concentrate

Mango juice concentrate is processed from mango juice or pulp as the base material. When the concentrate is derived from pulp, the pulp is subjected to polygalacturonase, pectinase, or cellulase enzymes to break down the pectins and cellulose. The juice concentrate has a sugar content of between 28 and 60% of °Brix) [8,30].

### 3.3. Mango Squash

Mango squash is a concentrated drink consisting of 25% juice, 45% TSS and 1.2 to 1.5% acidity with either sulfur dioxide or sodium metabisulfite as a preservative [31].

### 3.4. Cordials

Cordials are simply crystal-clear squashes obtained through filtration of the juice, using either special juice filters or a hygienic muslin cloth or strainer. Cordials have a TSS concentration of 12–14% of °Brix and 3.5% acidity, adjusted by addition of sugar and citric acid, respectively, and preserved by either sodium benzoate or sodium metabisulfite. Mango cordial can be produced on its own or blended with other fruits or vegetables such as pineapple or carrot juice.

### 3.5. Mango Nectar

Mango nectar is similar in composition to squash, except for the presence of a preservative in squash [32–34]. Mango nectar consists of 20–33% pulp content, TSS of 15°Brix and 0.3% acidity as citric acid, other ingredients (sugar, citric acid, vitamin C), and carboxymethylcellulose as a stabilizer.

### 3.6. Mango-Juice-Enriched Probiotic Dairy Drinks

Mango juice in combination with other fruit juices has the potential to be used as a new food matrix alternative to dairy products as a delivery vehicle for probiotics [35]. Mango juice improves the quality characteristics of fermented beverages and the viability of probiotics [36]. Mango pulp can also be used as a thickener or texture modifier or replacement for sugar in mango-flavored probiotic milk drinks [37–40].

### 3.7. Mango Wine

Mango wine is another beverage product derived from mango that can improve the value of mangos and reduce postharvest losses [41]. Due to its high sugar content (total soluble solids content > 16), mango pulp is an appropriate substrate for fruit wine fermentation [42]. The ethanol and aromatic components in mango wine have been shown to be comparable to those of grape. However, mango wine characteristics are affected by a number of factors including fermentation temperature, which affects not only the rate of yeast fermentation and duration but yeast metabolism. This in turn affects the chemical composition and the quality of the wine. The incorporation of sulfur dioxide, which is both an antioxidant and antimicrobial that is critical in inhibiting any spoilage microorganisms in wine production, can affect the volatile compound synthesis during fermentation such as increased acetaldehyde formation in mango wine. Furthermore, the type of yeast strain has an impact on the character and quality of mango wine) [43–45].

## 4. Dried Products

Dried mango products (slices or flakes) are generally prepared from ripe mangoes and dehydrated using a variety of methods including solar, hot-air cabinet, vacuum, spray, or freeze dryers. The dehydrated mango products are intended for either direct market or used in other formulations such as mango leather and powder [46–48]. The production process for dehydrated mango slices, dices, and chips are similar, other than the shape and size of the product. The ripe mango fruits are washed, peeled, pitted, and the pulp is sliced longitudinally into uniform thickness. The slices are then subjected to different specific pretreatments such as blanching, 0.5–1% citric acid, 0.2% ascorbic acid, and 40°Brix sugar to preserve product color and improve product stability. The pretreated slices are then dried at a temperature of 60–65 °C. Citric acid and ascorbic acid pretreatments before drying at 50 °C and 65 °C have the optimal outcome and produce the best physical quality parameters [49]. Different pretreatments prior to drying have significant effects on the moisture content, equilibrium relative humidity (ERH), water activity, and color parameters. Rehydration characteristics are affected by the different pretreatments with the



most effective being 0.5% citric acid having the maximum rehydration ratio and coefficient of rehydration [49]. The dried mango slices have better antioxidant properties compared to fresh, probably due to synergistic effects of polyphenols and flavonoids) [50].

#### 4.1. Mango Leather

Fruit leathers are dried sheets of fruit pulp which have a soft, rubbery texture and a sweet taste [51]. Leathers can be produced from a variety of fruits, although mango, apricot, banana, and tamarind leathers are amongst the most popular. Mango leather is produced by spreading the pulp evenly in a thin layer on a tray coated with vegetable oil to a depth of 1 cm and drying in mechanical or solar dryers to a final moisture content of 15–20% [51,52]. Solar drying can take a much longer time, leading to discoloration of the pulp. Addition of guar gum, pectin, and ascorbic acid reduces the discoloration of the mango leather. Preservatives such as sodium metabisulfite can be added to extend the shelf life [51]. Incorporation of sucrose, pectin, and maltodextrin reduced the drying rate of mango leather [8].

Mango leather can also be produced by refractance window drying (RWD) which is synonymous with cast-tape drying (CTD) [53,54]. This drying method is characterized by the fruit pulp that is to be dried being spread on a transparent polyester film, commercially known as Mylar (DuPont®). The lower surface of Mylar is kept in contact with hot water which supplies the heat for the product drying. RWD is a drying technique developed for drying of food pulp and purees to retain nutritional quality at relatively low processing temperatures with reasonable capital costs [55]. RWD of mango resulted in much shorter drying times and the mango leather obtained had better quality with higher nutrient retention compared to conventional drying. In addition, scanning electron microscopy showed that RWD resulted in powder particles of irregular shape and smooth surface with uniform thickness. On the other hand, tray and oven drying resulted in powder particles of corrugated, irregular, and crinkled surface with uneven shape and thickness [13].

#### 4.2. Mango Powder

Mango powder is used as a flavor enhancer in various foods and beverages such as in ice cream, yoghurt, and the bakery and confectionery industries. Dried mango powder is processed by dehydrating mango pulp to a moisture content of 3% moisture using spray, freeze, vacuum, or drum dryers. However, it has been demonstrated that physiochemical properties of Refractance Window®-dried mango (RW-M) powder are comparable to the freeze-dried counterpart and are better than drum- and spray-dried mango powder [56]. One of the challenges in obtaining physically stable powder from dry fruits is their susceptibility to caking during processing and storage [57]. Caking is characterized by powder agglomeration, consolidation, and adhesion and has a negative impact on shelf life of powder. Caking also results in poor rehydration, lower reduced sensory properties, and short shelf life. To mitigate caking and improve hygroscopic properties of powder, carrier agents such as maltodextrin, starch, cellulose, or gums are used at a concentration of between 1 and 20% dry basis [58].

Mango jams and jellies are semisolid gels, which are made using the same general process [8,59]. Both of these products are made from fruit pulp, with added sugar, pectin, calcium chloride, and citric acid. Jelly is a clear or translucent fruit spread made from sweetened fruit juice and set using naturally occurring pectin. It is made by a process similar to that used for making jam, with the additional step of filtering out the fruit pulp after the initial heating. The incorporation of stem extract of medicinal plant marjoram into mango jam inhibited food spoilage bacteria viz. *Bacillus cereus* and *Bacillus megaterium*, indicating its potential use as a natural preservative in mango jam production [60].

Pickles are made mostly from green mangoes in India and are categorized as salty, oily, or sweet pickle based on the type of preservation used. They can be produced from peeled or unpeeled fruit with or without stones and with different kinds of proportions of spices.

## 5. Utilization of Mango Processing Waste

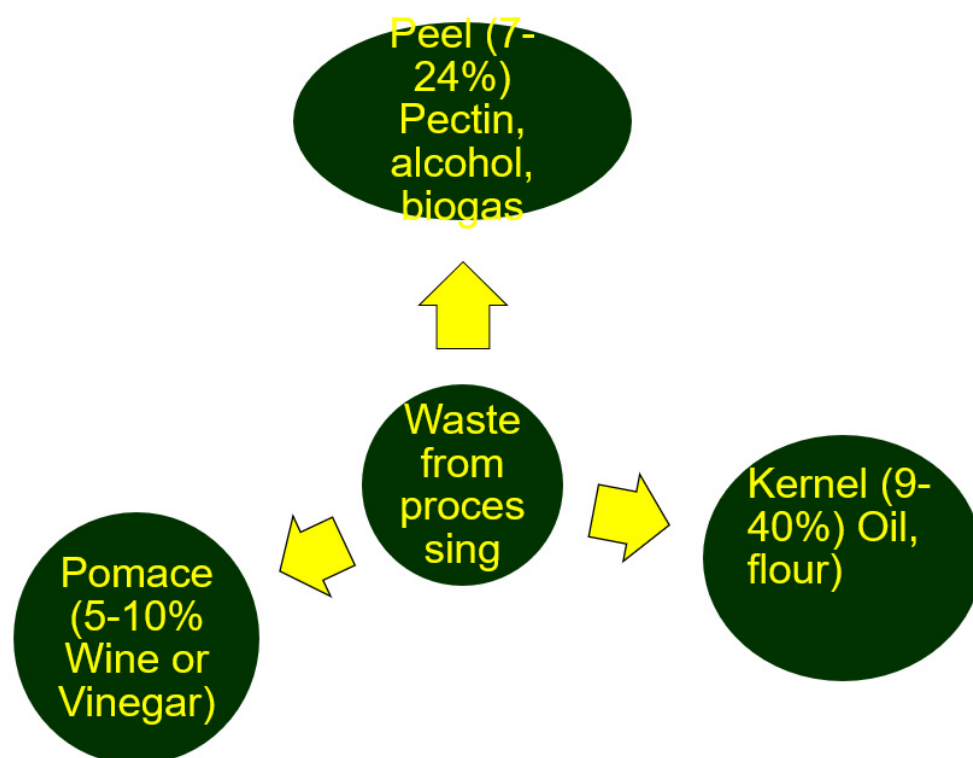
Mango processing and value addition generate an enormous amount of waste consisting of mainly the peels and the seeds, also known as stones [61–63]. Depending on the variety, 20–60% of the fruit weight comprises the seed while the kernel within the seed accounts for 45–75% of the seed's weight [64]. It has been reported that the mango seed is among the dominant agroindustrial wastes, generating about 123,000 metric tons of wastes annually in the world. Mango peels account for 7–24% of the fruit's weight [65,66]. Hence in general, mango processing generates millions of tons of solid waste approximated at 30–50% of the raw material. Furthermore, the volumes of mango processing waste are on the rise due to growth in the mango fruit production and processing industry [65]. The current standard waste disposal for industrial mango agro wastes and by products comprise of recovery (e.g., co product processing), recycling (e.g., internal upcycling of industrial side-streams into animal feeds or composting into manure), or solid waste disposal (e.g., into land fill or dried and incinerated as a source of energy) [66]. Food processing solid waste disposal has an adverse effect on the environment, such as water pollution, unpleasant odors, asphyxiation, vegetation damage, and greenhouse gas emissions. In addition, waste disposal is costly and adds to the total cost of production [67]. In addressing these challenges, there have been attempts to valorize the waste materials into value-added products.

The nutritional, physiochemical, and bioactive composition of mango seed and peels has been reviewed by Sharma et al., [68] and Mwaurah et al. [64]. There are some potential industrial applications of the value-added products derived from the seed and the peels as illustrated in Figure 2. The mango kernel contains about 15% of edible oil that is comparable to 18–20% oil content in soybeans and cotton seeds [64]. However, the oil from mango kernel comprises low free fatty acid and peroxide value and hence does not require further processing prior to consumption. Blending oil from mango kernel and palm oil in the ratio of 80:20 (*w/w*) produces an oil with palmitic, oleic, and stearic acids comparable to cocoa butter [64]. Oil from the mango kernel has been considered to be a novel, cheaper, and readily available alternative to cocoa butter due to its phytochemical and physicochemical properties. The seed kernel has also been demonstrated to have antimicrobial activity, probably due to high content in different phenolic compounds, fatty acids, tocopherols, squalene, and sterols [67]. The mango kernel contains anti-nutritional factors and has to be preprocessed by dehulling, washing, soaking, boiling, and drying. The dried kernels can then be ground into flour and used as a functional ingredient in bakery products due to the presence of essential vitamins such as provitamin A and vitamin E and antioxidant activities [69].

Mango peel is a major byproduct of the mango processing industry and it constitutes about 15–20% of the total weight of mango fruit. The peel has been found to be a good source of biologically active substances such as polyphenols, carotenoids, flavonoids, anthocyanins, dietary fiber, vitamin E, vitamin C, and enzymes and hence has a potential use as a functional food [18,70,71].

The peel has been demonstrated to have more polyphenols than the pulp, and has a potential use as a functional food that can be used to supplement various food formulations such as bakery products, ice cream, breakfast cereals, pasta products, beverages, and meat products. It can also be used as a replacement in products such as cream, cheese, and yogurt.

Mango peel has been demonstrated to be a substantive source of odor-active compounds, that could be revalorized and used directly as a flavoring ingredient or even as a natural source out of which volatile compounds could be extracted [72]. Both the extract and the peel byproduct itself would be feasible to be used in food and cosmetic industries to provide or enhance the mango aroma of the product [73–76].

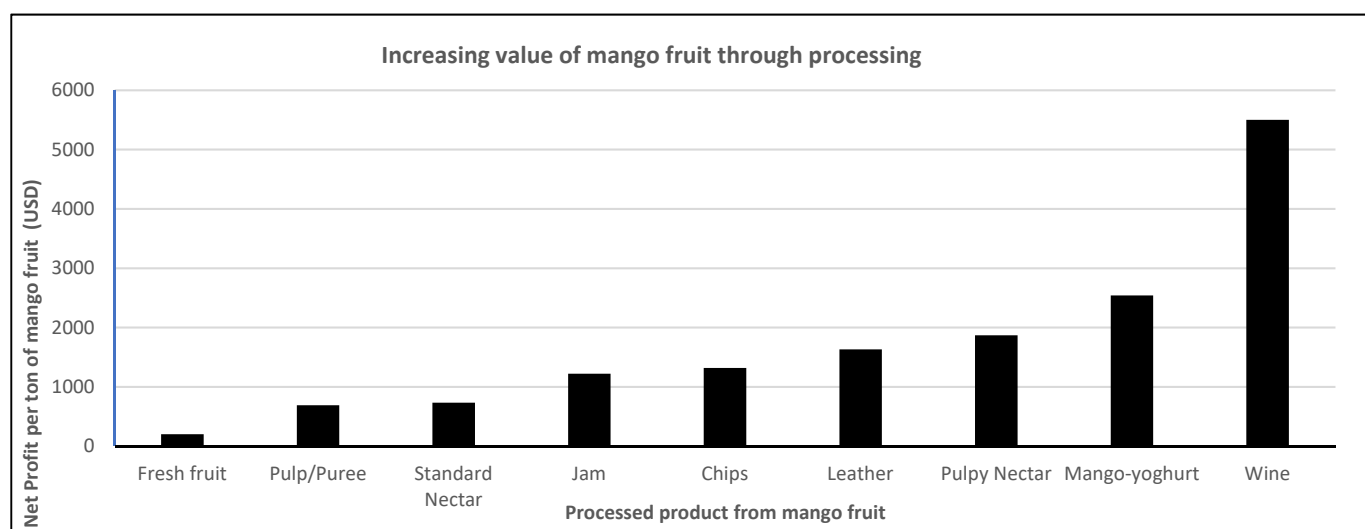


**Figure 2.** Utilization of mango processing waste.

#### 6. Increased Value from Processed Mango Fruit

Although marketing of mango as fresh whole fruit is the most common practice among small-scale farmers in developing countries, processing the fruit into nutritious and safe products has greater value as shown in Figure 2 below [77]. In the profit margin calculation described in the Figure 3, the most lucrative processed product from mango fruit is wine with a net profit of USD 5500 per ton of mango fruit. However, processing of mango wine requires a more sophisticated system to produce the quantity and quality required by the market. Besides, market entry for small-scale processors is a challenge because of competition with established market brands. Mango puree, which only requires capacity to pulp and pasteurize, is a common product for many small-scale processors but with the lowest returns. In the cited study, the net profit on pulp from one ton of fruit is USD 700. Drying (dehydration) of mango fruit into products such as chips and leather does not require sophisticated equipment or facilities. According to the cited study, the mango chips and leather can fetch a net profit of USD 1300 and 1600 for mango chips and mango leather, respectively. If drying follows good manufacturing practices that ensure preservation of quality (nutritional and aesthetic) and safety of the products, such products may be the most recommended ones for small-scale farmers/processors in developing countries.





**Figure 3.** Net profits (USD) derived from processing 1 ton of mango fruit into various products [77].

## 7. Conclusions

Mango fruit is a nutritious fruit that is commonly consumed in its fresh state. Processing it into the diverse products described in this mini review has potential to not only contribute to the amelioration of high postharvest losses reported in mango but also to making the fruit available to consumers all year round as nutritious and convenient products. In addition, proper market linkages and demand for the diverse products from mango fruit will ensure better returns for small-scale mango producers who are often exploited by traders who buy the fresh fruits at very low prices.

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