Report: Upcycling Mango Byproducts from Frozen Mango Processing into Valued Ingredients to the Personal Care Industry

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Proposed Aims

-To identify the waste products in frozen mango processing that can be upcycled to value-added ingredients, especially in the personal care industry

-To evaluate use of mango seed, oil expelled from the seed, mango butter, bioactive ingredients found in the peels of the mango, possibly medicinal properties in the branches/bark to better source waste into an appropriate processor/industry

-To identify evaluation methods in order to present supporting data of quality/effectiveness from mango waste products to support value in future experiments

Summary

Mango (Mangifera indica L.) makes up more than half of tropical fruits produced around the globe. The growing industry generates a significant amount of waste (i.e. by-products) during frozen fruit processing. Discarded parts of the mango include the kernel, skin, residual pulp/juice, and bark. Identifying novel uses for these by-product materials is beneficial for environmental sustainability and minimizing economic losses for the industry. Numerous biologically active components of the mango processing by-products have a potential of becoming valued ingredients by upcycling each waste stream into component parts that can be used in the personal care industry, especially in skincare. Previous research suggests that active components in mango, such as mangiferin, enhance skin appearance and texture. Other active components include vitamins, fatty acids, acids for exfoliating, and phenolic compounds with varied biological activities. Review of the processes by which these by-products can be extracted from by-product materials supports the future use of supercritical CO2 as a sustainable and "green" method of extraction. Current literature for utilizing mango by-

products needs more clinical studies investigating their potency for skin care use and ease for formulation. Potential for mango byproducts to enhance poultry feed by diversifying the fatty acid content and increase nutrient content is promising, though not necessarily a high value product.

Introduction

Food manufacturing industries account for 39% of food waste in developed countries, thus adding to environmental problems and costly disposal. (Jahurul et al. 2015) The presence of value components in agricultural food waste demands a review of potential uses for discarded by-products. The term “upcycle” is used to identify a waste material used to generate a product of equal or higher value. (Sung 2015) Upcycling minimizes waste and creates potential revenue for what would otherwise contribute to environmental pollution.

Mango (*Mangifera indica L.)* makes up 52% of the approximate 100 million tons of tropical fruit produced in 2018 globally, a 3.3% increase from 2017. (Altendorf, 2019) This valuable member of the *Anacardiaceae* family has over 1000 varieties grown in over 100 countries, including India, China, Thailand, Mexico, and Indonesia as the top producers. (Handbook of Mango Fruit, 2017) The value of the import market for mangoes increased from $513 million USD to $1.65 billion USD from 2000-2013, a 91.23% growth. (Handbook of Mango Fruit, 2017) The United States and the European Union are primary importers with 80% of Mexico’s shipments sold to the United States in 2018. (Altendorf, 2019)

With the increase of mango demand around the globe, mango processing by-products, seen as agro-industrial waste, continues to grow. Waste generated is about 210,000 metric tons annually, making the fruit to waste ratio between 25-40%. (Mwauruh et al 2020) Mango by-products include the seed (seed coat and kernel), peel, residual pulp/juice, leaves, and bark. The seed can account for 20-60% of the fruit mass and the kernel is 45-75% of the seed (Mwauruh et al. 2020, Martin et al. 2009). The fruit peel is reported as 7-24% of the fruit weight (Mwauruh et al 2020). Overall, about 42% of the fruit mass contributes to by-products, not including other agricultural waste such as leaves and bark. (Barbulova 2015)

Each by-product stream (i.e. seed, peel, residual pulp/juice, leaves, and bark) has been previously evaluated for active components and potential uses. Most scientific reviews were conducted through the lens of upcycling by-products via the food industry, with some mention of nutraceutical, pharmaceutical, and cosmetic application. (Kowlaska et al. 2017, Jahurul et al. 2015, Martin et al. 2009, Mwaurah et al. 2020, Singh et al. 2020, Puligundla et al. 2014, Serna-Cock et al. 2014) Overall, the use of mango by-product active components in the personal care industry is more valuable and profitable than in the food industry due to profit margins.

According to the United States Food & Drug Administration (USFDA), cosmetics are “articles intended to be rubbed, poured, sprinkled, or sprayed on, introduced into, or otherwise applied to the human body...for cleansing, beautifying, promoting attractiveness, or altering the appearance.” (*Cosmetics & U.S. Law*) Products can be defined as both a cosmetic and drug depending on claims made on their label; for example, sun protection claims require evaluation as a drug by the US FDA. Most products in the personal care industry are topical, affecting the skin, the human body’s largest organ, and promote protection, hydration, healing, or beautifying qualities such as improving fine lines and an overall youthful appearance. The range and content of phenolic compounds in extracts and oils derived from mango by-products makes mango an ideal candidate for upcycling these materials for the personal care industry.

Previous studies on mango and skin protection identified UVB defense and some wrinkle prevention by oral administration of mango in both animals and post-menopausal women. (Fam et al. 2020, Song et al. 2013) Levels of vitamins E, A, and C in mango act as antioxidants and have the potential to protect skin, while Vitamin C can aid the body in collagen production as well. Current studies on mangiferin, an abundant polyphenol in mango by-products, support previous findings of antioxidant and anti-inflammatory activity via efficient delivery methods to wounded skin and animal trials. (Allaw et al. 2020, Pleguezuelos-Villa et al. 2019) Studies determining a relationship between mango consumption and improved skin health further support a need for more studies using topical application in different formulations for cosmetic products.

Upcycling waste aligns with current personal care industry trends towards sustainability and environmental protection. Publications creating a sustainability calculator for the cosmetic industry (Bom et al. 2020), addressing corporate responsibility in the cosmetic industry (Fortunati et al. 2020), and reviewing sustainability in cosmetic products (Bom et al. 2020) highlight the trend to prioritize sustainability in the cosmetic industry. These publications further define the term "sustainability" to encourage industry to give tangible solutions rather than allowing companies to use it as a marketing tactic. It should be noted that further evaluation of methods for extracting value ingredients from mango waste will be discussed further in this publication. Utilizing mango by-products aids in removing pollution, but extraction methods can negate this benefit if solvents are overutilized and more pollution is created through these processes.

The goal of this review is to identify the by-products of frozen mango production and illustrate their potential use in the personal care industry as an upcycled product. By- products (seed, peels, residual pulp/juice, leaves, and bark) will be introduced by their components of value and subsequent research published on their effectiveness. Methods of extraction or processing for each component will be identified and evaluated based on potential effects on the environment. Potential uses and products will be identified to promote usage in the personal care industry; additionally, any gaps in the literature or opportunities for further evaluation will be noted. The personal care industry's utilization of mango waste will aid in creating a higher value product from what causes environmental pollution.

Mango Kernel

The Mango contains a single flat oblong seed that houses a single kernel within the endocarp. The endocarp can be fibrous or hairy on the surface, depending on the variety. The seed represents 10-25% of the whole fruit weight, and the kernel represents 45-75% of the seed or approximately 20% of the whole fruit weight in different varieties. More than one million tons of mango seeds are produced annually as a waste (Leanpolchareanchai et al 2014) The major components of mango kernel are carbohydrates (58-80%), lipids (6-16%) and high value protein (6-13%). The mango seed is also an excellent source of antioxidant phenolic compounds, vitamins and essential fatty acids making it an excellent target for upcycling for the personal care industry.

Mango kernel is rich with vitamins C, E, K, and A (**Table 1**). (Mwaurah et al. 2020) Vitamins are needed to maintain normal function of the skin. For example, dermatological signs of B vitamin deficiency include a patchy red rash, seborrheic dermatitis and fungal skin and nail infections. Deficiencies in vitamin C are characterized by skin fragility, bleeding gums and wound healing as vitamin C is involved in collagen formation. Vitamins C and E help protect against UV-induced damage (photoaging) of the skin. Vitamins can be delivered to the epidermal layer of skin by topical application, although the efficacy of the topical application is dependent on the formulation of the cosmetic preparation and can vary. Recently, microemulsion preparation of mango seed extracts (MSE) allowed MSE to penetrate skin layers up to 60-fold higher as compared with the controls. (Leanpolchareanchai, 2014)

Table 1. Vitamin content of mango by-products

Vitamins	**Amount**	**Mango Variety/Origin**	**Source**
Vitamin A	15.27 IU	N/A	(Mwuarah et al. 2020)
Vitamin E	1.30 mg/100 g		
Vitamin K	0.59 mg/100 g		
Vitamin B1	0.08 mg/100 g		
Vitamin B2	0.03 mg/100 g		
Vitamin B6	0.19 mg/100 g		
Vitamin B12	0.12 mg/100 g		
Vitamin C	0.56 mg/100 g	Ikanekpo (Nigeria)	(Arogba 1997)

Mango kernel oil (also known as mango butter) makes up 4-13% of the dried seed weight . (Fontanel, 2013; Janeš & Kočevar Glavač, 2018) Its fatty acid profile consists mainly of oleic, stearic, and palmitic acids, which account for up to 52-56% of the saturated fatty acid profile and 42-44% unsaturated fats. (Nadeem et al. 2016) (Kittiphoom et al. 2013) A summary of the fatty acid profile can be seen in **Table 2**.

Table 2. Fatty acid profile of mango kernel

Fatty Acids (% total fatty acids)	**Source (Mango Origin)**								
	Awolu and Manohar 2019 (India)	**Nahar et al. 2017 (Bangladesh)**	**Wu et al. 2015 (Miyazaki, Taiwan, Thailand, Philippines, Mexico)**	**Sonwai et al. 2014 (Thailand)**	**Sagiri et al. 2014 (N/A)**	**Kittiphoom and Sutasinee 2013 (Thailand)**	**Kittiphoom 2012 (N/A)**	**Arogba 1997 (Nigeria)**	**Augustin and Ling 1987 (Malaysia)**
Palmitic (16:0)	4.23-8.21	5.38-6.32	4.7-7.1	5.4	9	8.50-8.97	9.29	10.5	6.7-7.3
Stearic	28.59-40.38	37.91-40.70	34.2-57.5	46.6	39	37.37-38.50	39.07	27	44.3-44.4
Oleic	32.65-46.34	47.26-49.66	34.3-55.4	41.1	41	43.45-44.75	40.81	48.3	38.9-42.1
Linoleic	2.93-4.75	4.46-5.28	1.0-5.2		6	5.67-6.78	6.06	14.2	4.5-7.4
Linolenic		0.28-0.40	1.8-2.4		1	0.49-0.79	0.64		
Arachidic		0.86-1.74	1.3-2.7		2.5		2.48		1.6-1.8
Behenic		0.25-0.32			1		0.64		
Eicosenoic		0.08-0.52				2.19-2.51			
Lignoceric					0.5		0.49		
Margaric									0.12-0.17
Trans-9-eladic	8.13								
Arachidonic	1.63-3.06								

Ethyl Stearic	7.05

Mango kernel stands out from other sources of plant-based fats for its high phenolic content (9.87-16.93 mg/g), which exceeds that of competitors like avocado seed (8.82 mg/g) and tamarind seed (9.45 mg/g). (Nadeem et al. 2016) A summary of phenolic compound levels found in mango are seen in **Table 3**. High levels of phenolics in the extracted oil add value to this waste product and potential for being used as a cosmetic product.

Table 3. Phenolic content of mango by-products

Phenolic Compound	**Source (Mango Origin)**				
	Mwaurah et al. 2020 (N/A)	**Masibo and He 2009 (N/A)**	**Soong and Barlow 2006 (Singapore)**	**Arogba 2000 (Nigeria)**	**Arogba 1997 (Nigeria)**
Mangiferin	12.57 mg/g db	4.2 mg/100 g extract			
Catechin	4.36 mg/g db				44.8 g/kg raw kernel
Quercetin	0.52 mg/g db				
Gallic Acid		6.0 mg/100 g extract	20-838 mg/100g kernel	27.9% total tannins (1.78%w/w dry matter)	
Ellagic Acid			3.1-118 mg/100g kernel	11% total tannins (0.70%w/w dry matter)	
Tannin		20.7 mg/100g extract			
Coumarin		12.6 mg/100 g extract			
Vanillin		20.2 mg/100 g extract			
Cinnamic Acid		11.2 mg/100 g extract			
Ferulic Acid		10.4 mg/100 g extract			
Gallotannin				74.5% total tannins (4.75%w/w dry matter)	
Tannic Acid				46.6% total tannins (2.97%w/w dry matter)	
Epicatechin				2.7% total tannins (0.17%w/w dry matter)	

Potential Ingredients and Usage

Mango kernel oil (mango butter) is currently used in the personal care industry but is not as widespread as other oils or butters. Mango butter is valued for its significant potential as a cosmetic ingredient and is considered as a possible replacement for increasingly expensive coco butter and unpopular mineral-based emollients. (Cornily et al., 2010; Dhara, Bhattacharyya, & Ghosh, 2010) The pale-yellow color of mango kernel oil enables use in products without further manipulation for visual appeal. Comparisons to cocoa butter (Akhter et al. 2016) (Sagiri et al. 2014) and shea butter suggest use for mango butter in the cosmetic market, especially given that its unique total phenolic content supplies antioxidant capabilities for the skin.

Multiple uses as a skin curative were mentioned in Nadeem et al. 2016 including: dry skin, frost bites, rashes, blemishes, wrinkles, skin irritation, dermatitis, and stretch marks. Mango kernel oil was studied for its deodorizing capabilities, which suggested its potential as lotion and soap. (Wu et al. 2015) This study indicated positive qualitative measures, i.e. texture, moisturizing capability, and foaming properties, that suggest preference over commercial and olive oil based lotions and soaps by their 10 participants. One study in Bangladesh further evaluated mango kernel oil to ensure heavy metals or aflatoxin levels met their nation's standards for use as a cosmetic ingredient, which was the case. (Nahar et al. 2017) Other components of the mango kernel can be useful, such as the starch. Amylose content and swelling power suggest that starch from mango kernel has potential as a texturizing agent in personal care products. (Mwaurah et al. 2020)

Extraction Processes

Soxhlet extractions are common practice to obtain mango kernel oil from the kernel. (Kittitphoom et al. 2013) Supercritical CO_2 extraction has been used for obtaining fats from the mango seed (Awolu et al. 2019) (Kayathi et al. 2020) and further combining them with palm stearin to create cocoa butter equivalents. (Jahurul et al 2014) (Sonwai et al. 2014) Previous studies have used 50-60% solvent extraction with various parameters to obtain the bioactive compounds from mango kernel. (Mwaurah et al. 2020) Further description of processes and comparison of various methods can be found in **Table 4**.

Table 4. Method of extraction for components of interest in mango by-products*

METHOD	PROCESS	Well Established, Conventional Method	Relatively Simple and Low Cost	Time Efficient	Require Less Resources (i.e. solvent)	Relatively High, Good Quality Yield	Low Risk of Bioactive Degradation (by heat or time)
Soxhlet extraction	sample is placed into a porous thimble inside extraction chamber and continuously washed with solvent that is repeatedly distilled, and extract is collected in a flask	■	■				
Maceration	sample soaked in solvent and agitated at a selected temperature, time, and speed/frequency	■	■				
Microwave-assisted extraction (MAE)	sample placed in solvent and radiated inside microwave chamber at a selected power level, temperature, and time		■	■	■	■	
Ultrasound-assisted (sonication) extraction (UAE)	sample placed in solvent inside sonicator apparatus for a selected time and sonication frequency		■	■	■	■	
High Hydrostatic Pressure (HPP)	sample placed in solvent and inside pressurizing apparatus and treated at a selected temperature (typically room temperature), pressure, and time			■	■	■	■

Supercritical Water Extraction	sample extracted using water at temperature between 100-374°C at a pressure high enough to maintain liquid state (under 22 MPa)	

*Black box denotes that the method is associated with that column description

Gaps in Literature

Mango kernel and mango kernel oil are studied to quantify their phenolic content, but studies examining their use on skin are not available to determine bioavailability of the phenolics in this matrix.

Mango Peel

Mango peel is a common waste component in mango processing that comprises almost a fourth of the fruit's mass. The skin of the mango contains polyphenols, vitamins, and enzymes, even more than the pulp of the mango in the case of polyphenols. Total phenols vary from 31.85-100 mg/g according to various studies looking at various types of mangoes. (Serna-Cock et al. 2016) Other phenolic compounds found in mango can be seen in **Table 3**. Various enzymes are concentrated in mango skin, including protease, peroxidase, polyphenol oxidase, xylanase, and amylase. Pectin, carotenoids, and lactic acid are additional components that have been obtained from mango peel. Aroma compounds attributing to herbaceous, fruity, floral, and resinous smells are also highly concentrated in the skin. (Oliver-Simancas et al. 2020)

Potential Ingredients and Usage

Pectin is obtained from mango peel. (Puligundla et al. 2014) Pectin is commonly used as a thickening agent and preferred over gelatin if cosmetic products wish to label their products as "vegan". More innovative uses include pectin-based natural coatings. (Valdes et al. 2015) Pectin active coatings can be a replacement for plastic used in shrink wraps around bath products or soaps. Though this has not been thoroughly studied, its use as an edible coating suggests a biodegradable replacement in other industries. Subsequently, the addition of mango peel extract to active packaging in combination with fish gelatin films aids in scavenging free radicals, creating potential for additions to hydrogels used in cosmetic products such as masks or individual packaging for single-use serums or treatments as an antioxidant. (Adilah et al. 2018) Carotenoids from mango peel possess high Vitamin A activity. (Puligundla et al. 2014) Vitamin A derivatives are often used in cosmetics to promote cell renewal. Lactic acid, a chemical exfoliating ingredient in cosmetic products, can be produced with mango peels; two extraction methods have been cited, yielding 17.484 g/L and 63.33 g/L. (Puligundla et al. 2014) Some antifungal components of extract from mango peel have been identified, with the major component being 5- (12-heptadeconyl)-resorcinol. (Puligundla et al. 2014) Antifungal creams can be used cosmetically or as acne treatments for people with sensitive skin or fungal acne. Ferulic acid was quantified as a bound phenolic acid in ripe Raspuri mangoes up to 3.97 mg/g. (Ajila et al. 2013) Ferulic acid is often used in combination with vitamin C in cosmetic products for additional photoprotection and some stabilization of vitamin C to enhance shelf life.

Extraction Processes

Various extraction processes are used depending on the targeted component. Methods for processing the waste by-products were evaluated for levels of efficiency and extraction optimization. (Nagel et al. 2014) Supercritical CO_2 and pressurized ethanol have been used to extract bioactive components from the peel. (Serna-Cook et al. 2016) This process has been studied on mango juice by-products including peel, creating a concentrated polyphenolic powder with 90% of the polyphenols recovered using ethanol extraction. (Meneses et al. 2015) Comparisons of the soxhlet extraction with 95% ethanol and subcritical water extraction support utilizing subcritical methods to obtain polyphenols from mango skin using more green technology, as described in **Table 4**. (Tunchaiyaphum et al. 2013) Sonication at room temperature has been used to effectively extract mangiferin and lupeol from mango skin without degradation due to extraction conditions. (Ruiz-Montanez et al. 2014) Additionally, lactic acid production occurs with fermentation of the peel in *Lactobacillus casei*, but first using stem explosion and acid hydrolysis as a pretreatment. (Puligundla et al. 2014) Pectin extraction from mango peel uses sulfuric acid in water at 90°C for 2.5 hours to obtain 70% yield. (Valdes et al. 2015) Though this is efficient, the waste produced suggests a need for alternative greener methods of extraction.

Gaps in Literature

Bioavailability is an issue to address when extracting compounds from a natural source rather than synthesis, in that interactions between a target compound and other components can affect how efficiently the compound is used in application. Pectin could effectively be used to reinforce packaging for various cosmetic products, especially with the emergence of single-use products containing vitamin C, vitamin A, or other antioxidants that lose effectiveness with exposure to oxygen and air. Further studies are needed to identify how pectin can further aid in a sustainable and biodegradable packaging for single-use cosmetics. Soap products have been previously developed using mango peel or mango peel extract, though germicidal products are not as effective as commercial products or only physical properties were evaluated rather than antimicrobial properties. (Crebello et al. 2019) (Okunola et al. 2019)

Mango Residual Pulp and Juice

Wasted mango pulp or juice that is discarded due to residual inefficiencies of processing or visual impairment of the whole mango fruit can be used for its antioxidant capabilities. Freeze drying this waste can extend its shelf life to later be used as an ingredient in various products. (Chaisawadi et al. 2014) Odor active volatiles attributed to green, floral, or fruity aromas are identified in the pulp and have potential use as an added aroma in a product. (Oliver-Simancas et al. 2020) Residual pulp that would otherwise go to waste can be upcycled for added aromatic appeal in cosmetic products.

Mango Leaves

Mango leaves have various uses including dying cotton. (Ayele et al. 2020) Bioactuve components in mango leaf extract provide potential pharmacological uses, including as a diabetes treatment. (Kulkarni et al 2018) Various components of mango leaf extract were identified using supercritical extraction, including: gallic acid, mangiferin, iriflophenone glucosides, quercetin, and quercetin derivatives. (Guaman-Balcazar et al. 2017) Recent research has identified 36 polyphenolic tyrosinase inhibitors in mango leaf extract, 3 for the first time, that suggest potential for cosmetic products aiding the skin. (Shi et al. 2020) Tyrosinase inhibitors aid in preventing and correcting hyperpigmentation. Lupeol is a triterpene that inhibits cell growth in skin cancer. (Park et al. 2015)

Potential Ingredients and Usage

Fermented mango leaf extract can be useful, as its probiotic components can benefit children with allergic skin diseases. (Park et al. 2015) Park et al. 2015 verify that fermented mango leaves exhibit high polyphenol content and antioxidant activity with increasing concentrations, identifying potential for use in beauty products that feature fermented ingredients. Fermented beauty products often enhance brightening of skin, especially reducing hyperpigmentation, and protect from other free radicals.

Extraction Processes

Mango leaf extraction has been studied to optimize for mangiferin extraction using solvents. (Kulkarni et al. 2016) Mango leaf fermentation has been studied at larger scales, especially utilizing supercritical CO_2 and high pressure systems, rather than conventional solvent-only extractions. (Fernandez-Ponce et al. 2016) (Fernandez-Ponce et al. 2013) (Fernandez-Ponce et al. 2015) (Guaman-Balcazar et al. 2018) Ridding of unnecessary solvents is one aspect of a green chemistry approach to limit chemical waste going back into the environment. Benefits of utilizing certain methods can be found in **Table 4**.

Gaps in Literature

Though greener extraction methods have been recently optimized and developed, further formulation studies would be ideal to understand active ingredient application in products and their interactions with other ingredients. Fermented products especially are promoted in skincare with studies of the microbiome, especially for skin, coming into the discussion.

Mango Stem Bark

Stem bark of a mango tree contains significant levels of mangiferin, the predominant polyphenol in the mango plant. Mangiferin is attributed to being the active principle of mango extract. Mango stem bark extract has antiviral, antiseptic, antimicrobial, anti-inflammatory, and antioxidant uses, among others. (Ediriweera et al. 2017)

Potential Ingredients and Usage

In regards to cosmetics, mango stem bark extract through various formulations in skin products can enhance skin feel and protect through photoprotective and antioxidant properties. Hair and nails are also shown to be protected by products containing mango stem bark extract, such as a serum, as it reduces effects from heat stress. (Telang et al. 2013) Mangiferin demonstrates synergistic results with compounds such as sea buckthorn, maple sap, and coffee extract, which all might be found in cosmetic formulations. (Telang et al. 2013) Resin from mango bark has been used for healing cracked skin and feet in Bangladesh. (Ediriweera et al. 2017) A metabolite of mangiferin, norathyriol, was studied as a potential chemoprotective agent preventing skin cancer caused by UV light on mammalian cell lines. (Li et al. 2012)

Extraction Processes

Over 15 varieties of mango tree can be utilized for safe extraction of mangiferin from stem bark. Only water is used as the solvent in decoction. Drying the extract yields 10-15% of homogenous brown powder and the active principle is further used in formulations. (Núñez-Sellés et al. 2007)

Gaps in Literature

Few clinical studies on the effectiveness of mango stem bark extract and mangiferin have been completed in cosmetic or pharmacological applications. Mango stem bark extract has a long history of use in folk medicine in China, Cuba, and India.

Conclusion

Upcycling mango by-products in the personal care industry maximizes economic benefits and minimizes environmental costs. Mango products in the global import market have dramatically increased. (Mitra 2016) (Saúco 2017) Various research studies focus on understanding potential health benefits of mango by-products such as their vitamin and phenolic content. Mango-related production has a major role in the global market; thus it is necessary to improve the supply chain to effectively utilize wasted mango by-products to achieve a closed-looped economic goal.

Skincare market profitability would result in higher revenues for the mango farmers or processors as the margin for profit is much higher in cosmetic products than it is for food products. The existing supply chains for ingredient sourcing in the personal care industry are shifting to a transparent, sustainably conscious model. This model is driven by consumers demanding knowledge of how the products they buy are harming or benefitting the environment around them. Additionally, consumers want to understand the quality of ingredients in the products they buy and use. Consumers will pay a higher price point in order to support sustainability and contribute to making choices that support a healthy planet, while also seeing results.

On a sustainable level, more studies should focus on how to develop the quality of mango by-products by improving technology. In addition to a new revenue stream, the application of supercritical CO_2 extraction will not only relieve overutilization of solvents but also reduce environmental pollution to achieve zero waste moving forward. By opening this aspect of the market, the mango industry achieve a win-win situation in both a profitable market and a limited resource environment.

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