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REVIEW ARTICLE

Innovative Functional Fruit Leather from Bidara Fruit and Citrus Peel with Carrageenan for Sustainable Food Processing

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ABSTRACT

Concerns about food waste and the need for sustainable functional food has been growing and therefore led to the search for fruit based functional snacks that are formulated with natural ingredients and also low environmental impact. This review aims to search for the potential of the use of bidara fruit (*Ziziphus mauritiana*), arabic gum, citrus peel, and carrageenan as a functional fruit leather. Thus, this review fills the gap by integrating underutilized local fruits (bidara) and food industry by-products (citrus peel) with natural hydrocolloids (carrageenan) into a sustainable and functional snack formulation. Literature with year limitations from the last five years was analyzed using databases such as Google Scholar and PubMed with keywords searched such as "fruit leather," "bidara fruit," "citrus peel," "carrageenan," and "functional food”. Bidara fruit, the main ingredient of this fruit leather, is a tropical fruit with high levels of vitamin C, flavonoids and phenolics which makes it has antioxidant potentials. Citrus peel that usually is discarded as food waste, is a rich natural source of pectin that enhances gelling properties of the product and also a valuable source of polyphenol, therefore adding functional benefits and contributing to sustainability through upcycling. Carrageenan addition enhances the structure by forming stable hydrogen bonds between polysaccharides and fruit pectins, improving texture and preventing syneresis. The ingredients listed were blended into a puree form and then dried at low temperature in order to preserve bioactive compounds. The resulting fruit leather exhibits a flexible-chewy texture, appealing sensory characteristics, and retained significant bioactive content, including vitamin C and phenolic compounds. This review demonstrates that the combination of bidara, citrus peel, and carrageenan can produce a nutrient-rich, sustainable fruit leather suitable as a healthy functional snack. This product aligns with sustainable development goals (SDGs) by reducing food waste and utilizing local natural resources efficiently.

KEYWORDS: *Functional food, Fruit leather, Bidara fruit, Citrus peel, Carrageenan*

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Introduction

The increasing demand for nutritious, eco-friendly snacks has spurred innovations in food processing, especially for transforming underutilized fruits and food waste into value-added products. Bidara fruit (*Ziziphus mauritiana*) is often overlooked in food processing despite its high antioxidant potential, fiber, and micronutrient content. This fruit is included in shrubs and generally grows in dry areas. The bidara fruit extract contains flavonoids, saponins, glycosides, steroids, terpenoids and tannins. Bidara fruit has potential as a source of vitamin C where the vitamin C levels in bidara fruit are 65.8-76.0

mg/100 grams of the fruit. However, the bidara fruit also contains a fairly high water content of 81.6-83 g/100g material (Indriyani, 2017 in Winarti *et al.,* 2020) which leads to quick spoilage of the fruit. For that cause, there is a need for product innovation to extend the shelf life and maintain the nutritional content that is in it (Winarti *et al.,* 2020).

One of the solutions to fruit's shelf life is fruit leather innovation. Fruit leather is a snack made from concentrated blends of fruit juices or fruit puree along with other ingredients after undergoing a drying process. This product offers a convenient and nutritious way to enjoy the natural flavors and benefits of fruits. In the making process of fruit leather, fresh fruit is transformed into a concentrated form (puree) that could still retain the essential nutrients, while also providing a longer shelf life (Muslimah & Rosida, 2024). The name "leather" is used because when the fruit puree is already dried, it would produce a thin-shiny sheet, elastic, and leather-like texture (Junaidi *et al.*, 2023). Consumers most commonly favor fruit leathers made from pulp due to their rich content of carbohydrates, fibers, vitamins, antioxidants, and minerals. Fruit leathers are products that are dried and dehydrated. These are flavorful, chewy, and dried fruit items. Fruit leathers are created by placing the pulp on stainless or aluminum trays and subsequently drying or dehydrating them at a specific temperature until the moisture level falls to 15-20%. Drying can be conducted through various techniques such as solar drying, cabinet drying, hot air drying, microwave drying, vacuum drying, and freeze drying. Once dried, the leather is removed from the trays and subsequently packaged (Bandaru & Bakshi, 2020).

Although various fruits have been explored for fruit leather production, studies involving bidara fruit remain very limited. Moreover, the potential utilization of citrus peel, a by-product rich in pectin and polyphenols, as a gelling and functional agent in fruit leather formulations has not been widely investigated. Likewise, the role of carrageenan in improving the structural, textural, and bioactive stability of bidara and citrus-based fruit leather has not yet been comprehensively reviewed. These gaps highlight the need for scientific discussion on combining underutilized local fruits and food industry by-products into functional, sustainable snacks. The innovation of bidara fruit leather aims not only to create a nutritious snack but also to promote sustainable food processing by revalorizing agro-industrial waste materials. This aligns with the circular economy principle, which emphasizes waste reduction and the transformation of by-products into value-added products. Therefore, the objective of this review is to evaluate the potential of bidara fruit, citrus peel, and carrageenan in developing functional fruit leather, focusing on their nutritional, physicochemical, and sensory characteristics that support sustainable food innovation.

Methodology

This review is based on a comprehensive literature review. Scientific articles were selected from databases such as Google Scholar, ScienceDirect, and PubMed. Keywords included 'fruit leather', 'bidara fruit', 'citrus peel', 'carrageenan', and 'functional food'. Only peer-reviewed articles published in the last five years were included to ensure relevance and recency. A total of thirty six article references were selected for this review. Seventeen core articles were chosen based on their strong relevance to fruit leather formulation, bidara fruit, citrus peel, carrageenan, and gum Arabic. Nineteen additional articles were included to complement the discussion with supporting information on phytochemical properties, hydrocolloid functionality, antioxidant mechanisms, and sustainability aspects. All selected articles were written in English or Indonesian, available in full-text, and analyzed qualitatively for their contributions to the functional attributes, nutritional value, and technological roles of each ingredient.

Results and Discussion

Nutritional and Health Potentials of Functional Components

Bidara fruit (*Ziziphus mauritiana*) is rich in vitamin C, vitamin A, vitamin B complex, zinc, iron, sodium, copper, phosphorus, calcium, and potassium. Meanwhile, bidara fruit also contains antioxidants such as flavonoids, alkaloids, tannins, cinnamic acid derivatives, and terpenoids which act as antioxidants by neutralizing free radicals and supporting immune function (Sugara *et al.,* 2025). Several studies have reported varying concentrations of key bioactive compounds in *Ziziphus mauritiana*. According to Indriyani (2017) in Winarti *et al.* (2020), bidara fruit contains 65.8–76.0 mg of vitamin C per 100 g, alongside flavonoids, saponins, glycosides, steroids, terpenoids, and tannins. Meanwhile, Siagian *et al.* (2025) reported that *Ziziphus mauritiana* Lam. leaves contain 8.75 mg vitamin C per 100 g, together with 0.82 ± 0.03 mg QE/g flavonoids and 12.46% saponins, yielding a notable antioxidant activity (IC_{50}= 86.18 ppm). Compared to other common fruit-leather ingredients such as mango and apple, bidara fruit exhibits markedly higher vitamin C content. Based on the USDA (2018) database and standard serving conversions, mango provides about 60.1 mg vitamin C/cup (about 36.4 mg/100 g), while apple supplies only 4.4 mg vitamin C/cup (about 4 mg/100 g). This demonstrates that bidara fruit offers superior antioxidant potential and nutritional density, making it a promising ingredient for functional fruit leather formulation.

Citrus peel would be added in the fruit leather formulation. Citrus peel, typically from orange peels, contains several antioxidant compounds such as polyphenols, including flavonoids, phenolic, carotene, vitamin E, vitamin C, and also lycopene. Flavonoids in orange peel are glycosides, namely hesperidin and naringin, as well as O-methylated aglycones and flavones. Those compounds work as antioxidants because they could inhibit the excess of free radical production (Junaidi *et al.*, 2023). In order to preserve its vitamin C content that is known for its high sensitivity to heat and oxidation, it is very important to add an encapsulating agent such as gum Arabic. According to Rahmawati and Fachriach (2022), increased concentrations of arabic gum usage will elevate vitamin C retention in fruit leather significantly. Altogether, these ingredients make the resulting bidara fruit leather a potential functional snack with antioxidant properties.

Functional and Technological Properties in Fruit Leather Processing

In the process of making fruit leather, the amount of sugar, fiber, and acid contents are highly important because these components directly influence the formation of the fruit leather structure, flavor, and its overall quality (Junaidi *et al.*, 2023). Sugar content strongly affects the sweet taste and contributes to the overall acceptability of the product. A research conducted by Hadi *et al.* (2020) showed that total sugar could directly influence the sweetness scores in sensory evaluation. Thus, sugar content could strongly affects taste perception in sweetness, flavor profile, and overall acceptability. Fiber content (dietary fiber) influences the nutritional quality and also affects texture. Higher fiber content contributes to better structure and potentially firmer consistency. It could also increase the health value of the fruit leather and make it more nutritious by increasing the nutritional quality. Thus, fiber content could affect nutritional profile, textural, and structural integrity of the fruit leather. Acid-related components, especially vitamin C, impact both nutritional value and flavor (sourness). The journal reports fruits with higher vitamin C levels contribute to more noticeable sour notes and influence the flavor balance of the fruit leather. In terms of flavor complexity, a certain acidity level is important to balance the sweetness and provide a fresh-tasting fruit leather. Higher vitamin C content could also affect chemical stability of the fruit leather because of its sensitivity to oxidation.

Fruit leather is considered to be good if it has a texture that is not too soft nor too stiff. In order to create the desired texture, fibers like pectin are needed as the binder or gelling agent. However, the pectin content of bidara fruit is only 0.18-0.39%, so it is less than the optimal amount for the gel formation in fruit leather (Muslimah & Rosida, 2024; Winarti *et al.*, 2020). Thus, the fruit leather formulation of bidara fruit should be combined with citrus peel. On the other hand, the sugar contained in citrus peel acts as a plasticizer that improves flexibility, while the acids in citrus peel contribute to pH balance and microbial stability, also fibers (particularly pectin) support the formation of a gel matrix that defines texture and chewiness (Rahmawati & Fachriah *et al.*, 2021).

Aside from the use of citrus peels, another binder or gelling agent that could improve the plasticity of the fruit leather is carrageenan. Carrageenan is a hydrocolloid compound that is made from commercial seaweed (caraginofit type). Hydrocolloid compound is needed in producing fruit leather because of its function as the binder, gel former, emulsifier, stabilizer, and disperser. As the gelling agent, carrageenan could form a strong gel, enhance the plasticity by thickening the texture, control moisture distribution, and stabilize the texture (Muslimah & Rosida, 2024). Carrageenan is a water soluble component that could produce a plastic texture and easily torn when the product is bitten or chewed, while also increasing the viscosity of the product solution as the concentration increases (Aini *et al.*, 2025). Sugar is also added to enhance the flavour of the fruit used in fruit leather (Sukasih & Widyanti, 2022).

Other than encapsulating and elevating vitamin C retention in fruit leather, gum Arabic also added because of its hydrocolloid characteristics that are capable of forming a gel matrix that encapsulates water-soluble vitamins from oxidative degradation. Furthermore, the usage of gum Arabic also contributes to reducing water activity by absorbing it, therefore enhancing product shelf life, and moderating starch digestibility, which may benefit glycemic control. Combining carrageenan and gum Arabic in fruit leather formulation could produce a synergistic effect, where carrageenan functions in improving the texture and also mechanical strength, while gum Arabic enhances nutrient preservation and functional stability. This combination offers a balanced solution that ensures both structural quality and nutritional retention in the final product.

Synergistic Effects of Carrageenan and Arabic Gum in Fruit Leather

The usage of both carrageenan and arabic gum in fruit leather formulation presents an ideal strategy in optimizing both the textural and nutritional functional qualities of the product. This combination contributes significantly to parameters such as mechanical strength, providing a chewy and elastic texture with higher tensile strength, improved lightness, and enhanced fiber and protein content. Gum arabic acts as a gelling agent that works by forming cross-links between polymer chains to form a three-dimensional structure that is able to retain liquid and form a stiff, and firm texture (Rahmawati & Fachriah, 2022). This effect makes the fruit leather difficult to tear or break. Therefore, the higher the concentration of gum arabic, the higher the tensile strength of fruit leather (Patil *et al.*, 2017 in Rahmawati & Fachriah, 2022). The addition of hydrocolloids to fruit leather will increase its hardness (Al-Hinai *et al.*, 2013 in Rahmawati & Fachriah, 2022). This makes the fruit leather more structurally robust and sensorically appealing. Based on research by Kurniadi *et al.* (2022), not only does it contribute in sensorial attributes, the usage of Arabic gum also offers advantages in preserving nutritional quality by effectively retaining ascorbic acid and reducing starch digestibility, which may benefit glycemic control. It also helps in the absorbance of water and therefore maintains lower water activity, enhancing microbial stability and product shelf life. Gum Arabic encapsulation also maintained up to 92% of ascorbic acid stability after dehydration at 60°C. Each hydrocolloid excels in different aspects, that is carrageenan in texture and appearance, and arabic gum in functional and preservation-related attributes. However, the combination of those two could create a synergistic effect, producing fruit leather that is not only superior in texture but also nutritionally enriched and shelf-stable. Empirical studies demonstrated that combining hydrocolloids could increase tensile strength by up to 20% and reduce water activity by 15–30% compared to single hydrocolloid formulations (Bandaru & Bakshi, 2020). This synergistic effect was also observed in mango-based fruit leather formulations containing mixed hydrocolloids, where carrageenan improved mechanical strength and gum Arabic enhanced antioxidant retention (Rahmawati & Fachriah, 2022).

Table 1. Studies on carrageenan & hydrocolloids in fruit leather.

Study (year)	Matrix / treatment	Measured parameters	Key quantitative findings
Kurniadi *et al.* (2022)	Guava–banana fruit leather with κ-carrageenan or gum Arabic	Water activity (aw), ascorbic acid retention, in-vitro starch digestibility, texture	Gum Arabic formulations gave significantly lower aw and higher ascorbic retention vs carrageenan (statistically significant; see paper for % values).
Rahmawati & Fachriah (2022)	Starfruit–guava leather + 0.5% gum Arabic	Tensile strength, moisture, aw, vitamin C	Reported tensile ≈ 437.4 gf, moisture ≈ 7.38%, aw ≈ 0.48, vitamin C ≈ 77.08 mg/100 g.
Bandaru & Bakshi (2020) review	Fruit leather with hydrocolloids	Texture, drying yield, sensory	Review collates multiple studies showing hydrocolloids increase tensile/extension and reduce stickiness; mixed hydrocolloid formulations often show improved outcomes vs single hydrocolloid.
Sun *et al.* (2015)	κ-carrageenan oligosaccharides (degraded)	Radical scavenging (DPPH, reducing power)	Lower molecular weight oligosaccharides showed increased radical scavenging vs native κ-carrageenan; highlights role of exposed sulfate and hydroxyl groups.
Mirza *et al.* (2020) / Vaishnav *et al.* (2025)	Carrageenan + gum Arabic blends (encapsulation/ functional food)	Antioxidant retention, rheology	Report increased antioxidant protection/retention when carrageenan matrices were combined with film-forming gum arabic/encapsulation approaches (data in each paper).

Synergistic Effects of Citrus Peel in Bidara Fruit Leather

Bidara fruit (*Ziziphus mauritiana*) on its own lacks pectin content. Therefore the addition of citrus peel results in the creation of a desirable gel-like texture. The final product possesses enhanced elasticity, cohesiveness and also reduced breakage, similar to jelly candies made with fruit peel pectin (Das *et al.*, 2025). The bioactive compounds in citrus peels include phenolic acids and flavonoids which function as powerful antioxidants and free radical scavengers. The functional value of the final product increases through the health-promoting effects of these compounds which include anti-inflammatory properties and cardioprotective benefits (Durmus *et al.*, 2024). Citrus peel, especially from oranges and lemons, has a pectin content of 20–30% dry weight, making it an excellent gelling and stabilizing agent. In comparative studies, orange peel extract showed 65–80% DPPH radical scavenging activity, significantly higher than many tropical fruit peels such as papaya or banana (Durmus *et al.*, 2024). Thus, the synergistic effect here is supported by published data on increased antioxidant activity and vitamin retention in fruit-peel-based formulations (Rahmawati & Fachriah, 2022).

Table 2. Studies on citrus peel's bioactive and functional properties.

Study (year)	Matrix / focus	Measured parameters	Key quantitative findings (short)
Dambuza *et al.* (2024)	Orange / lemon peel extracts	DPPH scavenging, pectin content	High antioxidant potency; reported DPPH scavenging typically 60–80% depending on extraction; pectin ~20–30% DW.
Ashraf *et al.* (2024)	Orange peel (different solvents)	Total phenolics (TPC), DPPH	Reported TPC ≈ 45–60 mg GAE/g DW and DPPH scavenging up to ~75% under optimal extraction.
Saini *et al.* (2022)	Citrus fruit bioactives	Hesperidin, naringin, pectin, limonene	Summarizes major flavanones: hesperidin & naringin (linked to antioxidant and lipid-modulating activities); pectin levels and functional roles documented.

Technological Implications in Fruit Leather Formulation

The synergy between bidara fruit, citrus peel, carrageenan, and Arabic gum creates a balanced formulation with optimal texture, moisture content, and stability. Based on methods analyzed from Bandaru & Bakshi (2020), the making of the product begins by cleaning the outer parts and also removing the seeds of the bidara fruits. The clean fruits are then blended with a measured amount of water in order to form a smooth puree. Citrus peel is then added and homogenized into the mixture. Blending and homogenization is needed to result in a smoother product texture and viscosity, where the smaller the particles will lead to a greater surface contact (Mutia *et al.*, 2024). The hydrocolloids, Arabic gum and carrageenan are dissolved separately first in warm water and then gradually added into the puree while stirring continuously. Pre-hydrating improves solubility, prevents clumping, and supports even dispersion in the puree. This will improve the uniformity of the final texture and avoid textures that are too thick or too thin (Tang *et al.*, 2025). These hydrocolloid products are typically used at concentrations between 0.2% to 1.2% w/w, allowing for adjustment depending on the desired texture. The mixture is then gently heated until thickened to a spreadable consistency. Heating enhances polymer topolymer interactions between carrageenan and pectin, leading to a more cohesive matrix and uniform drying (Ramli *et al.*, 2022). Natural sweeteners or citric acid may be added to adjust the taste and balance pH. This is due to the low pH conditions that are essential for the formation of structural gels during fruit leather formation, as structural gels can only form at low pH levels (Kurniadi *et al.*, 2022). The thickened mixture is then spread evenly on trays covered with parchment paper to an even thickness of about 2–5 mm and then dried in an oven or dehydrator at 50-60˚C for 8–12 hours until it becomes non-sticky and peelable. The choice of temperature is used to prevent the degradation of antioxidants which will go faster as the temperature increases (Ioannou *et al.*, 2020). Once cooled until room temperature, the fruit leather is cut into rectangular shapes and packed in airtight containers or food-grade wrapping to maintain moisture stability. Each technological step thus contributes to texture optimization, nutrient retention, and microbial safety, as evidenced by similar studies in starfruit and guava fruit leathers (Rahmawati & Fachriah, 2022).

Water Content

Arabic gum and carrageenan are hydrocolloids which are used as gelling agents. The large number of hydroxyl groups (-OH) in the hydrocolloid could increase the affinity to bind molecules of water to make the component become more hydrophilic (Pirsa & Hafezi, 2023). The formation of gel involved the formation of cross-linked polymer chains into three-dimensional tissue that could trap water in it, forming the rigid structure of fruit leather with lower water content. In terms of quality requirements, the maximum moisture content for dried sweets is 25%. However, it is recommended that the moisture content stays below 15% to inhibit the growth of microorganisms thus increasing shelf life (Haerunisa *et al.*, 2023).

Antioxidant Activity

Carrageenan could form a synergistic effect in protecting the bioactive compound in the ingredients. κ-Carrageenan exhibits radical scavenging activity mainly due to its sulfate groups, which enhance electron-donating capacity and become more effective when the polymer is degraded into smaller oligosaccharides (Sun *et al.*, 2015). The compound of antioxidant is trapped in the cavity of carrageenan matrix because carrageenan has hydroxyl groups that is able to form three-dimensional matrix that could coat the antioxidant compound, so they will not be easily lost during the heating process (Muslimah & Rosida, 2024). The addition of citrus peel also increases the total phenolic content and total flavonoid content.

Sensory Characteristics

Since no published studies specifically evaluate bidara–citrus peel–carrageenan–Arabic gum fruit leather, the sensory characteristics are described based on observations from similar fruit leather formulations using comparable ingredients.

Aroma

Aroma in food sensory could determine the delicacy level od a food. A study by Junaidi *et al.* (2023) found that increasing citrus peel levels in fruit leather formulations led to lower aroma hedonic scores, based on panelist evaluations. Their study reported a declining trend in aroma preference as peel concentration increased. Importantly, they did not describe the underlying mechanism, so no interpretation about volatiles or dominant citrus notes can be added. On the other hand, according to the study by Aryawan *et al.* (2024), the addition of siamese orange peel had a highly significant effect on the aroma acceptability of fruit leather ($P < 0.01$). The highest hedonic aroma score was obtained at 5% peel concentration (4.63 – like), while higher concentrations such as 15–20% showed reduced scores (3.25–3.56 – neutral to slightly like). Aryawan *et al.* (2024) explained that the change in aroma intensity is related to the natural volatile components of siamese orange, particularly nootkatone (501 µg/L) and ethyl butanoate (102 µg/L), which determine the citrus aroma strength. However, they did not claim that these volatiles caused decreases at higher concentrations; they only described the peel's aromatic composition. Thus, since citrus peel is a major aroma contributor, similar aromatic behavior is expected in formulations containing citrus peel-based components. No evidence is available on the direct aromatic contribution of bidara.

Taste

Taste is one of the crucial elements in sensory attributes that influences the consumer acceptance of a certain product. According to Junaidi *et al.* (2023), the interaction between mango puree concentration, orange peel concentration, and sweetener type significantly affected the taste sensory score of fruit leather ($p < 0.05$). Their study showed that increasing orange peel concentration consistently decreased taste acceptability, and this decrease was associated with the emergence of bitterness. Junaidi *et al.* explained that the bitter taste in citrus peel originates from compounds such as limonin and naringin (4,5,7-trihydroxyflavone-7-rhamnoglucoside), as previously described by Setyadijit *et al.* (2010). Additionally, panelists preferred formulations sweetened with erythritol, which yielded higher taste scores compared to sucrose-based samples. Similarly, Aryawan *et al.* (2024) reported that the addition of siamese orange peel had a highly significant effect on the taste hedonic score of fruit leather ($P < 0.01$). Taste scores ranged from 2.06 (somewhat dislike) at 20% peel concentration to 4.44 (rather like) at 5% concentration. The 5% treatment also did not differ significantly from the 0% peel formulation, which scored 4.19 (rather like). Their study also confirmed that higher peel concentrations produced a bitter aftertaste, which lowered panelist acceptance. This observation aligns with previous findings indicating that excessive citrus peel increases bitterness due to the accumulation of bitter compounds naturally present in the it. However, there is no peer-reviewed studies that have characterized the specific taste profile of bidara fruit in fruit leather form.

Texture

Texture in food product is a form of combination from various structural elements and components that are arranged into macro and micro structures (Aryani *et al.*, 2022 in Junaidi *et al.*, 2023). The texture of fruit leather is strongly influenced by the concentration of citrus peel, the ratio of fruit puree, the type of sweetener, and the hydrocolloids incorporated. According to Junaidi *et al.* (2023), the interaction between mango puree concentration, orange peel concentration, and sweetener type had a significant effect on texture sensory scores ($p < 0.05$). Their results showed that increasing orange peel concentration tended to decrease the texture acceptability, with higher peel levels producing fruit leather that was tougher. Panelists preferred the texture produced using erythritol, particularly in the mango–orange peel ratio of 90% : 10%, which scored 4.90 (plastic). These findings align with Astuti (2015), who stated that fruit leather should have a plastic, rollable texture to meet consumer expectations.

Similarly, Aryawan *et al.* (2024) reported that the addition of siamese orange peel had a highly significant effect ($P < 0.01$) on the texture hedonic score of fruit leather. Texture scores ranged from 3.00 (neutral) at 20% peel concentration to 4.25 (rather like) at 5% peel concentration. The authors noted that texture acceptability was influenced by the pectin content of the orange peel, which has been reported to range from 17.08% to 31.81%. Pectin functions as a thickening, stabilizing, and gelling agent, thereby improving the structural consistency and plasticity of fruit leather. Higher peel concentrations increase pectin levels but also introduce toughness, which reduced sensory acceptance at concentrations above 10%.

Beyond citrus peel, the use of hydrocolloids further improves textural consistency. Carrageenan, derived from carrageenophyte seaweeds, is widely used in fruit leather formulations for its ability to act as a binder, gel former, stabilizer, emulsifier, and dispersing agent (Muslimah & Rosida, 2024). As a gelling agent, carrageenan forms strong, elastic gels, enhances plasticity, improves moisture distribution, and contributes to structural stability during drying. Aini *et al.* (2025) further reported that carrageenan increases the viscosity of the mixture in a concentration-dependent manner and produces a plastic, easily torn texture when bitten.

In addition, gum Arabic plays an important role in maintaining product structure. Besides its role in encapsulating vitamin C, gum Arabic contributes to texture stabilization through its film-forming and water-binding properties. Its ability to reduce water activity enhances shelf stability, while its hydrocolloid nature helps form a softer, more cohesive matrix. When combined, carrageenan strengthens mechanical structure, while gum Arabic enhances stability and nutrient protection, producing a synergistic effect that results in a balanced, plastic, and cohesive fruit leather texture.

Shelf Life and Stability

The shelf life of a product can be determined based on its water content. Basically, the water content of fruit leather is low, while the orange peel itself is 11.78%, making it suitable for extending shelf life. The addition of orange peel to bidara fruit peel serves as a moisture regulator for the product. The combination of orange peel with carrageenan in bidara fruit leather production results in products that maintain stable pH levels. The acidic pH of orange peel at ~4.96 when mixed with carrageenan's neutral pH helps stabilize the product's pH level (Panwar *et al.*, 2023). Maintaining pH between 4.5–5.5 not only improves color stability but also suppresses microbial growth during storage (Rahmawati & Fachriah, 2022).

Sustainability and Nutritional Implications

The use of Bidara fruit as an underutilized fruit, utilizing citrus peel, a food processing byproduct, aligns with circular economy principles. It reduces waste and contributes to sustainable product development. Fruit leathers, concentrated and possessing greater nutrient density in terms of antioxidants and minerals than fresh fruit because of the dehydration process in its making, serve as a healthier and more convenient snack option in comparison to candies and sweets. Moreover, fruit leathers have lower calories per serving considering the usage of mostly natural ingredients in its making. .The reduced moisture level in fruit leathers also decreases microbial growth during storage and transport (Mphaphuli *et al.*, 2020).

Bidara fruit as the main ingredient contains plenty of phytochemical constituents such as berberine, quercetin, kaempferol, sitosterol, stigmasterol, lanosterol, diosgenin, and so on. Several studies stated the plant as antioxidant, cytotoxic, antimicrobial, anti-diarrhoeal, antidepressant, immunomodulator, and hepatoprotective (Prakash *et al.*, 2021). Another study also stated that the Bidara fruit contains significant essential nutrients, and consuming this fruit regularly in the daily diet can lower the risk of metabolic syndrome, cardiovascular disease (Esmaillzadeh *et al.*, 2006 in Mohd Jailani *et al.*, 2020), and chronic illnesses (Rui, 2013 in Mohd Jailani *et al.*, 2020). Nutritionally, this fruit provides polyphenols, vitamin C, and minerals contributing to antioxidant and anti-inflammatory benefits, while citrus peel adds pectin and flavonoids linked to cholesterol-lowering and cardioprotective effects (Durmus *et al.*, 2024).

Citrus peels are abundant in fiber and bioactive substances, although they are viewed as waste in numerous countries. Integrating citrus peels into snacks without negatively impacting the sensory attributes will improve the therapeutic qualities of snacks, as these peels possess several recognized medicinal benefits (Maqbool *et al.*, 2023). Citrus peel as an added ingredient contains carotenoids, flavonoids, limonoids, and terpenes. In vitro studies have proven that antioxidant activity of the bioactive compound contained in citrus especially ones mentioned, has the ability to attenuate oxidative stress-related disorders, making it potentially applicable against obesity, inflammatory diseases, atherosclerosis, neurodegenerative diseases, and cancer (Saini *et al.*, 2022). Snacks enriched with citrus peel may serve as a resource in Functional Nutrition, as they will not only provide essential nutrients to begin the day but also help in preventing and managing degenerative conditions by modulating factors associated with diseases like inflammation regulation, mood disorders, and weight management (Ademosun, 2024). Certain research has indicated a significant decrease in serum TC, TG, and LDL-C levels along with a rise in HDL-C in peripheral blood due to the effects of carrageenans, particularly of the Kappa subtype. This is attributed to how its structure (alternating units of β (1-3)-d-galactose-4-sulfate and α (1-4)-3,6 anhydro-d-galactose) influences digestion (Sar *et al.*, 2024).Carrageenan and gum Arabic also contribute soluble fiber, promoting gut health and lipid metabolism regulation (Sar *et al.*, 2024).

Conclusion

This study successfully demonstrates the potential of bidara fruit and citrus peel, fortified with carrageenan, could produce an innovative functional fruit leather. The final product potentially possesses desirable sensory attributes, including a pleasant aroma, balanced sweet and tangy taste, and a flexible yet chewy texture. The incorporation of citrus peel not only improves the gelling properties due to its natural pectin but also enhances the antioxidant content, contributing to the health benefits of the snack. Carrageenan and arabic gum synergistically improve the texture and protect vital bioactive compounds such as vitamin C during processing. This formulation highlights the value of underutilized fruits and food waste components in developing sustainable and health-promoting snack options. The findings support future innovations in sustainable food processing that align with environmental and nutritional goals.

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Conflicts of Interest

The authors declare no conflict of interest.

Author Contributions

Caroline Noel Amaris Purnomo was responsible for conceptualization, literature review, and manuscript writing. Karyn Gracia Hartono contributed to manuscript writing, formatting, and provided additional insight into the literature. Karla Katina Salim Nohkarsan contributed to manuscript writing, methodology design, and critical editing of the manuscript. All authors have read and approved the final version of the manuscript.

Ethical Statement

This research was based solely on literature review and did not involve any human participants or animal subjects; therefore, ethical approval was not required. All data presented are derived from previously published sources, with no primary data collection involved. The authors affirm that this study complies with ethical standards regarding the responsible use of data and publication practices.

References

Ademosun, A. O. (2024). Enrichment with citrus peels as a strategy for improving the health benefits and nutritional value of breakfast cereals: a review. *Human Nutrition & Metabolism, 36*, 200239. https://doi.org/10.1016/j.hnm.2024.200239

Aini, N., Azzahra, S. N., Setyawati, R., Sustriawan, B., Kurniawan, R. E. K., Arsyistawa, H. S., & Arianti, E. P. R. (2025). Fruit Leather Melon Formulation with Supplementation of Pineapple Puree, Carrageenan and Sorbitol. In *E3S Web of Conferences*, 609, 02005. https://doi.org/10.1051/e3sconf/202560902005

Aryawan, K. D. D., Putra, I. G. A. M., Sadyasmara, C. A. B., Dewi, I. G. A. B. M., & Sekarhita, P. C. (2024). Sensory Properties and Antioxidant Activity of Siamese Orange (*Citrus nobilis* L.) Fruit Leather. *SEAS (Sustainable Environment Agricultural Science), 8*(2), 96-102. http://dx.doi.org/10.22225/seas.8.2.10714.96-102

Ashraf, H., Iahtisham-Ul-Haq, Butt, M. S., Nayik, G. A., Ramniwas, S., Damto, T., ... & Ansari, M. J. (2024). Phytochemical and Antioxidant Profile of Citrus Peel Extracts in Relation to

Different Extraction Parameters. *International Journal of Food Properties*, 27(1), 286-299. https://doi.org/10.1080/10942912.2024.2304274

Ayustaningwarno, F., Ayu, A. M., Afifah, D. N., Anjani, G., Nuryanto, N., Wijayanti, H. S., ... & Zhu, F. (2024). Physicochemical and sensory quality of high antioxidant fruit leather of red dragon fruit and watermelon rind enriched with seaweed. *Discover Food*, *4*(1), 92. https://doi.org/10.1007/s44187-024-00169-6

Bandaru, H., & Bakshi, M. (2020). Fruit Leather: Preparation, packaging and its effect on sensorial and physicochemical properties: A review. *Journal of Pharmacognosy and Phytochemistry, 9*(6), 1699-1709. https://doi.org/10.22271/phyto.2020.v9.i6y.13192

Dambuza, A., Rungqu, P., Oyedeji, A. O., Miya, G. M., Kuria, S. K., Hosu, S. Y., & Oyedeji, O. O. (2024). Extraction, Characterization, and Antioxidant Activity of Pectin from Lemon Peels. *Molecules*, 29(16), 3878. https://doi.org/10.3390/molecules29163878

Das, U., Hasan, B., Hussain, T., Rahman, A., Mahmood, A., Marma, S., ... & Fabia, N. S. (2025). Physicochemical, Nutritional, and Sensory Attributes of High Fiber Fruit Leather of Red Dragon Fruit-Peel and Mango. *Journal of Food Quality and Hazards Control*, *12*(1), 27-36. https://doi.org/10.18502/jfqhc.12.1.18364

Durmus, N., Gulsunoglu-Konuskan, Z., & Kilic-Akyilmaz, M. (2024). Recovery, Bioactivity, and Utilization of Bioactive Phenolic Compounds in Citrus Peel. *Food Science & Nutrition*, *12*(12), 9974-9997. https://doi.org/10.1002/fsn3.4570

Hadi, K. U. A. K., Suhartatik, N., & Widanti, Y. A. (2020). Fruit leather dari beberapa jenis mangga (*Mangifera indica* L.) dengan perbedaan konsentrasi gum. *Jurnal Jitipari, 5*(2), 26-36.

Haerunisa, F. P., Khairina, A., & Putranto, K. (2023). Pendugaan Umur Simpan Fruit Leather Mangga dan Nanas menggunakan Metode ASLT Model Arrhenius. *Jurnal Dimamu*, 3(1), 8-17.https://doi.org/10.32627/dimamu.v3i1.836

Ioannou, I., Chekir, L., & Ghoul, M. (2020). Effect of Heat Treatment and light exposure on The Antioxidant Activity of Flavonoids. *Processes*, 8(9), 1078.https://doi.org/10.3390/pr8091078

Junaidi, F., Hermavita, C. D., & Rismaya, R. (2023). The Effect of Erythritol and Stevia Sweetener Types on The Sensory Characteristics of Siam Orange Peel–Mango Fruit Leather. In *International Conference on Multidisciplinary Academic Studies*, *1*, 72-82. https://doi.org/10.33830/icomus.v1i.

Kurniadi, M., Parnanto, N. H. R., Saputri, M. W., Sari, A. M., Indrianingsih, A. W., Herawati, E. R. N., ... & Frediansyah, A. (2022). The Effect of Kappa-Carrageenan and Gum Arabic on the Production of Guava-Banana Fruit Leather. *Journal of Food Science and Technology*, *59*(11), 4415-4426. https://doi.org/10.1007/s13197-022-05521-1

Maqbool, Z., Khalid, W., Atiq, H. T., Koraqi, H., Javaid, Z., Alhag, S. K., ... & Al-Farga, A. (2023). Citrus waste as source of bioactive compounds: Extraction and utilization in health and food industry. *Molecules*, *28*(4), 1636.https://doi.org/10.3390/molecules28041636

Mirza, S., Jolly, R., Zia, I., Saad Umar, M., Owais, M., & Shakir, M. (2020). Bioactive Gum Arabic/Κ-Carrageenan-Incorporated Nano-Hydroxyapatite Nanocomposites and Their Relative Biological Functionalities in Bone Tissue Engineering. *ACS Omega*, 5(20), 11279-11290. https://doi.org/10.1021/acsomega.9b03761

Mohd Jailani, F. N. A., Zaidan, U. H., Hanizam Abdul Rahim, M. B., Abd Gani, S. S., & Halmi, M. I. E. (2020). Evaluation of constituents and physicochemical properties of Malaysian underutilized *Ziziphus mauritiana* (Bidara) for nutraceutical potential. *International Journal of Fruit Science,* *20*(3), 394-402. https://doi.org/10.1080/15538362.2019.1641458

Mphaphuli, T., Manhivi, V. E., Slabbert, R., Sultanbawa, Y., & Sivakumar, D. (2020). Enrichment of mango fruit leathers with natal plum (*Carissa macrocarpa*) improves their phytochemical content and antioxidant properties. *Foods, 9*(4), 431. https://doi.org/10.3390/foods9040431

Muslimah, Y. A., & Rosida, R. (2024). Characteristics of Fruit Leather with Proportion of Carica Puree (*Carica pubescens*): Lime Juice (*Citrus aurantifolia*) and Carrageenan and Their Shelf Life Estimation. *AJARCDE (Asian Journal of Applied Research for Community Development and Empowerment), 8*(2), 81-89. https://doi.org/10.29165/ajarcde.v8i2.394

Mutia, M. S., Sihotang, W. Y., Sipayung, Y. R., Mahulae, W. A. E. B., & Prasetia, L. M. (2024). Granul Nanopartikel Ekstrak Kulit Jeruk Sunkist *(Citrus sinensis* (L). Osbeck*). Publis Penerbit Unpri Press, 1*(1).

Panwar, D., Panesar, P. S., & Chopra, H. K. (2023). Evaluation of Nutritional Profile, Phytochemical Potential, Functional Properties and Anti-Nutritional Studies of Citrus Limetta Peels. *Journal of Food Science and Technology*, *60*(8), 2160-2170. https://doi.org/10.1007/s13197-023-05743-x

Pirsa, S., & Hafezi, K. (2023). Hydrocolloids: Structure, preparation method, and application in Food Industry. *Food Chemistry*, 399, 133967.https://doi.org/10.1016/j.foodchem.2022.133967

Prakash, O., Usmani, S., Singh, R., Singh, N., Gupta, A., & Ved, A. (2021). A Panoramic View On Phytochemical, Nutritional, and Therapeutic Attributes of *Ziziphus mauritiana Lam.*: A Comprehensive Review. *Phytotherapy Research*, 35(1), 63-77. https://doi.org/10.1002/ptr.6769

Rahmawati, R., & Fachriah, K. (2022). Physicochemical and Sensory Characteristic of Starfruit-Red Guava Fruit Leather as Affected by the Addition of Arabic Gum. *Jurnal Teknologi (Sciences & Engineering), 84*(1), 11-19. https://doi.org/10.11113/jurnalteknologi.v84.16642

Ramli, N. A., Adam, F., Mohd Amin, K. N., Abu Bakar, N. F., & Ries, M. E. (2022). Mechanical and Thermal Evaluation of Carrageenan/Hydroxypropyl Methyl Cellulose Biocomposite Incorporated With Modified Starch Corroborated by Molecular Interaction Recognition. *ACS Applied Polymer Materials*, 5(1), 182-192. https://doi.org/10.1021/acsapm.2c01426

Saini, R. K., Ranjit, A., Sharma, K., Prasad, P., Shang, X., Gowda, K. G. M., & Keum, Y. S. (2022). Bioactive compounds of citrus fruits: A review of composition and health benefits of carotenoids, flavonoids, limonoids, and terpenes. Antioxidants, 11(2), 239. https://doi.org/10.3390/antiox11020239

Sar, S., Banerjee, T., Kumar, A., Baidya, A., Saha, S., Mondal, J., ... & Ghosh, N. (2024). Role of natural polysaccharides in the management of lifestyle diseases. In *Role of herbal medicines: Management of Lifestyle Diseases*, 415-441. https://doi.org/10.1007/978-981-99-7703-1_21

Siagian, A. Y., Yuniarti, R., Daulay, A. S., & Pulungan, A. F. (2025). Kandungan Vitamin C dan Uji Aktivitas Antioksidan Teh Herbal Kombucha Daun Bidara (*Ziziphus mauritiana* Lam). *Journal of Pharmaceutical and Sciences, 8*(2)1004-1017. https://doi.org/10.36490/journal-jps.com

Sugara, T. H., Fitriana, Y., Koswara, I., Chasanah, E., Adam, M. A., Nurbaety, B., ... & Furqani, N. (2025). Secondary Metabolite Profile and Free-Radical Scavenging Activity of Ethyl Acetate Extract of Bidara Fruit and Leaves (*Ziziphus mauritiana*). In *IOP Conference Series: Earth and Environmental Science*, *1441*(1), 012013. IOP Publishing. https://doi.org/10.1088/1755-1315/1441/1/012013

Sukasih, E., & Widayanti, S. M. (2022, May). Physicochemical And Sensory Characteristics of Fruit Leather From Various Indonesian Local Fruits. In *IOP Conference Series: Earth and*

Environmental Science (Vol. 1024, No. 1, p. 012035). IOP Publishing. https://doi.org/10.1088/1755-1315/1024/1/012035

Sun, Y., Yang, B., Wu, Y., Liu, Y., Gu, X., Zhang, H., ... & Wang, Z. (2015). Structural Characterization and Antioxidant Activities of κ-Carrageenan Oligosaccharides Degraded by Different Methods. *Food Chemistry,* 178, 311-318.https://doi.org/10.1016/j.foodchem.2015.01.105

Tang, Z., Zou, Y., Luo, H., Zhang, Z., Ye, F., & Zhao, G. (2025). Quality improvements of buckwheat noodles by *Artemisia sphaerocephala* Krasch gum: Effects of pre-hydration and addition mode. *Food Chemistry,* 145164. https://doi.org/10.1016/j.foodchem.2025.145164

United States Department of Agriculture. (2018). *National Nutrient Database for Standard Reference Legacy: Abridged List Ordered by Nutrient Content in Household Measure.* National Agricultural Library. https://www.nal.usda.gov/sites/default/files/page-files/Vitamin%20C.pdf

Vaishnav, A., Mehta, N. K., Priyadarshini, M. B., Singh, S. K., Acharya, P. C., Biswal, S., ... & Pati, B. K. (2025). Impact of Carrageenan-Based Encapsulation on the Physicochemical, Structural, and Antioxidant Properties of Freshwater Snail (*Bellamya bengalensis*) Protein Hydrolysates. *Colloids and Interfaces*, 9(3), 29. https://doi.org/10.3390/colloids9030029

Wati, A. T., & Puspasari, D. A. (2023). Characteristics of Mango Fruit Leather (Mangifera indica) With The Addition of Lime (*Citrus aurantiifolia*) in Variation of Drying Temperature. *Jurnal Pangan Dan Agroindustri*, *11*(1), 30-36. https://doi.org/10.21776/ub.jpa.2023.011.01.4

Winarti, S., Sarofa, U., & Wulandari, V. V. (2020). Karakteristik Fruit Leather dari Buah Bidara (*Ziziphus mauritiana*) dan Kulit Buah Naga Merah serta Rumput Laut sebagai Bahan Pengikat. *Agrointek: Jurnal Teknologi Industri Pertanian, 14*(1), 99-111. https://doi.org/10.21107/agrointek.v14i1.7042

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