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Research Article

Analysis of value-added products developed from bael (*Aegle marmelos*)

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Abstract

Aegle marmelos, commonly known as bael or stone apple, is a tree native to India and Southeast Asia, with every part of the plant being useful for medicinal and food products. The pulp of the bael fruit is sweet, slightly astringent, aromatic, and pale orange in color. The research aimed to develop value-added products using this underutilized fruit, specifically a fruit bar (B-I) and jelly (B-II). These products were prepared from bael pulp, sugar, pectin powder, citric acid, food color, and sodium benzoate as a preservative. Sensory and physicochemical evaluations were conducted, including moisture, ash, pH, acidity, TSS, and phytochemical analysis of phenols, flavonoids, tannins, saponins, and alkaloids. FTIR spectroscopy was used to analyze functional groups, while the antioxidant potential was tested *via* DPPH assay. The sensory evaluation indicated that the jelly (B-II) had slightly higher overall acceptability (7.81 ± 0.93) compared to the fruit bar (B-I) (7.54 ± 1.72). The products contained significant bioactive compounds, with B-I exhibiting higher phenol (2.87 ± 0.04 mg/g) and flavonoid (2.82 ± 0.22 mg/g) content due to higher pulp concentration. The DPPH radical scavenging activity was higher in B-I (69.5 ± 11.36%) compared to B-II (54.4 ± 4.59%). B-II had the highest sugar content (6.87 ± 0.79 /100 g). Both products were deemed acceptable and offered a nutritious snacking option.

Keywords: *Aegle marmelos*, Phytochemicals, Product development, Sensory evaluation, Underutilized.

Introduction

The Rutaceae family fruit *Aegle marmelos* (L.) Correa (Bael) is a widely grown fruit plant in subtropical and tropical regions of southeast Asian countries including India, Sri Lanka, Pakistan, Myanmar, Bangladesh and Thailand. Bael is grown all over India, where it's also referred to by other common names including Bengal quince, sriphal, belo, bili, and bilva (Gupta *et al*., 2023). Because of its high nutritional value (proteins, carbohydrates, vitamins, and minerals) and the presence of numerous phytochemicals that contribute to its high medical value, bael fruit has been the focus of extensive research in recent years (Sharma *et al*., 2022). The medium-sized, slowly growing *A. marmelos* is a deciduous tree that grows to a maximum height of 12 to 15 m. The tree has a short trunk, and soft, thick bark that flakes, occasionally prickly branches, with the lower branches drooping (Kawra *et al*., 2022). Assessing fruit's phytochemistry revealed a wealth of phytochemicals, particularly flavonoids, coumarins, phenols, essential oils, and alkaloids, and their remarkable ability to treat a wide range of illnesses naturally (Bhar *et al*., 2019; Sarkar *et al*., 2020). *A. marmelos* acquires antidiarrhoeal, antiviral, radioprotective, antimicrobial, anticancer, antipyretic, ulcer healing, chemopreventive, diuretic, antifertility, antigenotoxic and anti-inflammatory characteristics that enable it to have an impact on the treatment and prevention of numerous diseases (Monika *et al*., 2023; Rahman & Parvin, 2014).

A. marmelos is an underutilized fruit but is a great source of biologically active ingredients that may find use in local culinary and medical applications. In addition to polyphenolic elements, it is also a great source of mucilaginous polysaccharides (Sharma *et al*., 2024). Psoralen and marmelosin are two therapeutically significant compounds found in the mucilaginous pulp of bael fruit. Psoralene is beneficial for skin conditions, particularly leucoderma, and provides protection from sunshine. Marmelos is helpful for conditions relating to the stomach and works effectively as a diuretic along as a laxative (Garg *et al*., 2021). Moreover, with its great flavor and medicinal and nutritional qualities, bael fruit has commercial potential for processing into herbal medicines and food products. Few food products have been formulated from bael pulp such as sherbet squash,

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jam, preserve, candy, etc., in addition to a range of Ayurvedic medicines (Baral & Upreti, 2016; Panda *et al*., 2014). Bael is still a fruit that is underappreciated despite having great flavor, nutritional value, and therapeutic promise for the functional food industry. Since bael is a seasonal fruit, it cannot be utilized all year round. As a result, it has the potential to add economic value by processing it to create a variety of products. Its hard shell, sticky texture, and abundance of seeds may also contribute to its lower popularity compared to other table fruits. Therefore, additional processing is required to make the fruit easily consumable so that it can be developed into a functional food product (Khanal *et al*., 2023).

There aren't many commercial products in the market, according to the reports, but a drink produced with bael fruit is cooling. Since many of the food products made from bael are novel to consumers, it is imperative that additional food products be brought to market and their economic worth assessed. Health-promoting foods are becoming more and more popular among consumers. This has further influenced customer preference for plant-based products and raised demand for nutrient-rich, healthful foods that can improve society's general health. This will promote the expansion of the bael processing industry in addition to providing new avenues for optimizing the utilization of robust, high-yielding fruit. Since fruit-based baked goods are becoming more popular these days (Shukla *et al*., 2024) beal pulp can also be employed in processed foods. However, from the references it was analyzed that there are research gaps involving the value-added product development of utilizing bael fruit for human usage. Thus, more research in this area is required to significantly and safely utilize this underutilized fruit.

Materials and Methods

Chemicals and reagents

The following analytical grade reagents were collected for different experiments, e.g., gallic acid, Folin-Ciocalteau reagent (FCR), sodium carbonate (Na_2CO_3), sodium nitrite ($NaNO_2$), aluminum chloride ($AlCl_3$), sodium hydroxide (NaOH), Dragendorff's reagent, chloroform, lead acetate, tannic acid, DNS reagent, DPPH reagent, potassium bromide (KBr) ethanol, methanol, phenol, hydrochloric acid, sulfuric acid, 3,5-dinitrosalicylic acid, phenolpthalein indicator and distilled water.

Raw material

Bael fruits were purchased from a vendor at a local market in Gomti Nagar, Lucknow and were found to be fully mature, ripe, yellowish, and of acceptable quality. Sugar, citric acid (E-330), sodium benzoate (E-211), pectin powder [E-440(i)] and food color were purchased from a grocery store.

Extraction of bael fruit pulp

The process began with thoroughly washing the fruits to remove any dirt or impurities. Once cleaned, the tough outer skins, or exocarps, of the fruits were gently broken into two halves to expose the inner pulp. To extract this pulp, a stainless-steel spoon was used to gently scoop it out from the fruit halves. After scooping, the pulp was blended manually to achieve a uniform consistency. To ensure that any seeds were removed, the blended pulp was strained through a stainless-steel sieve. This step filtered out any remaining seeds and other solid particles. Finally, the smooth, seed-free pulp was transferred from the sieve into a stainless-steel container which can be used for further processing.

Preparation of products

Bael fruit bar (B-I)

About 1-kg bael fruit pulp and 200 g sugar were taken in a pan and placed on the gas so that the sugar dissolves. After that, 100 g of pectin powder was mixed with water in the pan. The mixture was stirred continuously while boiling till the pulp thickened and slightly changed in color. After the flame was turned off, 10 g citric acid, 0.25 g sodium benzoate preservative and a pinch of orange food color were added and mixed. The aluminum tray was covered with butter paper and the cooked bael mix was poured into the tray and spread out uniformly to allow them to dry. Drying was carried out in sunlight for 15 to 16 hours and a tray was covered with muslin cloth to prevent any contamination in the product. After drying, the fruit bar pieces (Figure 1) were cut with a knife in a rectangular shape.

Bael jelly (B-II)

Over 1-kg bael fruit pulp and 400 g sugar were taken in a pan and mixed on a low flame until the sugar dissolved completely. In a separate pan, 200 g pectin powder was mixed with 500 mL water and continuously stirred on a low flame to avoid the formation of lumps. The pectin mixture was cooked for a few minutes until it formed a uniform thick mixture. Then the cooked bael sugar puree was added to the pectin mixture and mixed on a medium flame. The mixture was cooked until a desired consistency. After the flame was turned off 0.25 g sodium benzoate and a pinch of yellow color was added and mixed properly. The jelly was tested for sheet and wrinkle test to check that the consistency of the jelly was appropriate for the setting. Then the mixture was poured into silicon molds (Figure 1) and kept in the refrigerator for cooling and jellification. After the jelly was set it was taken out from the mold and stored in a cool and dry place.

Sensory analysis

Sensory evaluation offers the opportunity to procure a complete examination of the different properties of food

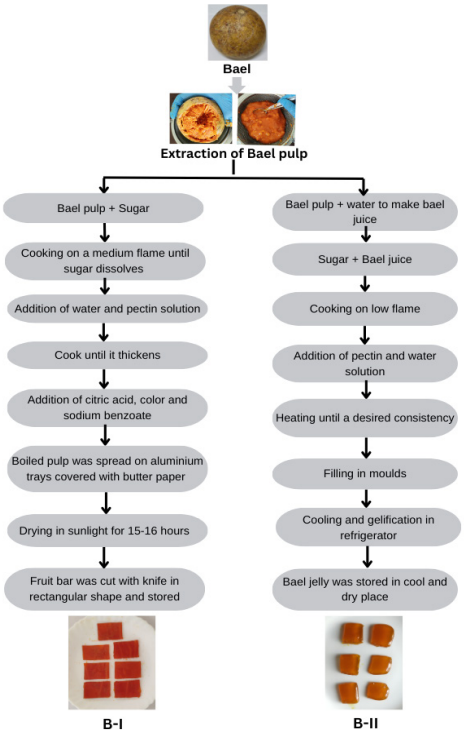

Figure 1: Flowchart for the preparation of products

as perceived by human sense. The sensory properties of the prepared items were evaluated using the hedonic rating test (Table 1). The sensory attributes of both the product samples were analyzed by an untrained sensory panel consisting of eleven panelist members from the institute comprising students in the age group of 20 to 25 around the university campus. The panelists were healthy and free from tobacco. The panelists evaluated the sensory attributes like aroma, color, taste, sweetness, texture/mouthfeel and overall acceptance using a 9-point hedonic scale where 9 was the highest score and 1 was the lowest. Before the sensory tests, the panelists were briefed about the scorecard. The panelists were given individual samples that were coded to avoid any potential influence on their responses from other panelists. Every panelist had a comfortable seat in a separate booth that was distraction-free and equipped with light.

Physicochemical analysis

All the experiments were performed in triplicates. All data are expressed as the mean ± standard deviation.

Determination of moisture

Over 3 g sample was placed in a moisture dish that had been previously dried and tared. The dish containing the sample was kept in the oven for 3 hours at 105°C. The dish was transferred to the desiccator to cool after drying and it was then weighed. The process of heating, cooling and weighing was repeated until the difference

Table 1: Sensory quality characterization of prepared products

Sensory attributes	*Sample*	
	B-I	*B-II*
Color	7.90 ± 0.28	7.81 ± 0.57
Aroma	6.36 ± 1.72	6.72 ± 1.48
Taste	7.63 ± 1.61	7.27 ± 1.13
Sweetness	6.72 ± 1.42	7.00 ± 0.95
Texture/mouthfeel	7.72 ± 0.96	7.09 ± 1.44
Overall acceptability	7.54 ± 1.72	7.81 ± 0.93

Note: Values are mean ± SD of the panellists scores

between two successive weighings was less than 1-mg. The lowest weight was recorded.

$$Moisture\ \% = \frac{(W1 - W2)}{W1} \times 100$$

where W1 = weight in grams of sample before drying
W2 = weight in grams of sample after drying.

Determination of pH

For estimation of pH, 10 g of sample was dissolved in 10 mL distilled water and a slurry was prepared thereof. The pH of the slurry was determined using a pH meter with a combined glass electrode. First, the pH meter was calibrated using standard buffer solutions at pH 4.0 and 7.0. After that, electrode was washed with distilled water and wiped with tissue paper. The electrode was dipped in sample solutions until a constant pH was recorded.

Determination of total soluble solids

For thick products, a suitable quantity (10 g) of sample was dissolved in 100 to 150 mL of distilled water. The contents of the beaker were heated to boiling for 2 to 3 minutes stirring with a glass rod. The beaker was cooled and the mixture was filtered through a filter paper in a dry vessel. The filtrate was reserved for determination. The refractometer was calibrated with a drop of distilled water and then the prism was wiped with tissue paper. A small quantity of the test solution (2–3 drops) was placed on the prism of the table-top digital refractometer. If the determination has been carried out at a temperature other than 20 ± 0.5°C the following corrections are required.

Determination of titratable acidity

A known weight of the sample was dissolved in boiling water and mixed thoroughly on a hot plate. The mixture was cooled and made up to a known volume. The mixture was filtered to remove any insoluble material before an aliquot was taken. An aliquot of the sample prepared was diluted with recently boiled distilled water. Then it was titrated with 0.1 N NaOH using 0.3 mL 1%

phenolphthalein for each 10 mL of the solution to pink end point which persisted for 30 seconds.

$$Acidity(\%) = \frac{Eq.wt.of\ acid \times Normality\ of\ NaOH \times Titre\ value \times Volume\ made\ up \times 100}{Wt.of\ sample\ taken \times Aliquot\ taken \times 1000}$$

Determination of ash

The crucible and lid were weighed up to 3 decimal places. About 3 g of sample was taken into the crucible. The crucible with the lid closed was placed into a muffle furnace at 550°C for 5 hours. After the sample turned gray, the crucible was cooled in a desiccator and ash from the crucible and lid was weighed.

$$Ash(\%) = \frac{Weight\ of\ ash}{Weight\ of\ sample} \times 100$$

Phytochemical analysis of sample

Preparation of sample extract

With some modification, the (Halim *et al*., 2022) method was utilized to extract phenolic chemicals from product samples. One gram of each sample was mixed with 19 mL of methanol and ethanol (v/v) at 100% concentration. The mixture was stirred at 400 to 500 rpm for 30 minutes at room temperature using a magnetic stirrer. The resultant slurries were filtered through a Whatman filter paper (No.41) and stored at −4°C temperature for further analyses.

Qualitative analysis

Test for alkaloids

A few drops of Dragendorff's reagent were added to 1-mL of each sample extract. This was noticed in the formation of an orange-red precipitate.

Test for terpenoids

Over 1-mL chloroform was mixed with 2.5 mL of sample extract and 1.5 mL concentrated sulphuric acid was cautiously added to form a layer. This was observed for the reddish-brown coloration of the interface.

Test for saponins

A method reported by (Banso & Adeyemo, 2006) was used to determine saponins. To check for persistent foaming, 0.5 mL of sample extract and 3 mL of hot distilled water were combined in a test tube and rapidly shaken continuously for a minute.

Test for tannins

A few drops of 10% lead acetate solution were added to 5 mL of each sample extract. This was noticed for the development of white precipitate.

Test for flavonoids

To 2 mL of extract, two to three drops of sodium hydroxide were added. When a few drops of diluted HCL were added, the initially bright yellow hue eventually turned colorless, suggesting the presence of flavonoids.

Test for phenols

The sample extract was combined with 4 mL of sodium carbonate, and 5 mL of Folin-Ciocalteau reagent. The tubes were vortexed for 15 seconds and then left to stand at 400°C for 30 minutes for color development. Phenols are indicated by the appearance of blue color.

Quantitative analysis

Total phenolic content

The sample extracts were tested for their total phenolic content (TPC) using a modified spectrophotometric method with the Folin-Ciocalteu reagent as an oxidizing agent and gallic acid as a standard (Rahman *et al*., 2024). For the standard curve, a volume of 0.15 mL of Folin-Ciocalteau reagent and 0.5 mL of 7.5% Na_2CO_3 solution was added to 50, 100, 150, 200 till 500 µg/mL concentrations of gallic acid solution in test tubes and mixed properly. Then, the mixture was incubated for 1-hour at room temperature in dark conditions. The absorbance was measured at 760 nm and the standard curve was plotted. For samples, 500 µL of sample extract was combined with 500 µL distilled water and the rest of the procedure is the same as the standard curve.

Total flavonoid content

Total flavonoid content (TFC) was measured by the colorimetric method as described by (Rahman *et al*., 2024) with slight modification. About 1-mL of the extracted sample was taken in a falcon tube and diluted with 4 mL of distilled water. Then 0.3 mL of 5% $NaNO_2$ was added to it and mixed properly. After 5 minutes, the sample mixture was allowed to react with 0.3 mL of 10% $AlCl_3$ and stand for 1-minute at room temperature. Then 2 mL of 1 M NaOH and 2.4 mL of distilled water were added to the sample mixture. After that, the mixture was kept in the dark for 15 minutes at room temperature. Finally, the absorbance was taken at 510 nm using a UV-visible spectrophotometer. The total flavonoid content was expressed as mg/100 g of sample.

Total tannin content

The tannins were determined by the Folin-Ciocalteau method. About 0.1 mL of sample extract was added in a test tube containing 7.5 mL of distilled water and 0.5 mL of Folin-Ciocalteau reagent, 1-mL of 35% sodium carbonate solution and diluted to 10 mL with distilled water. The mixture was thoroughly agitated and left at room temperature for 30 minutes, a group of standard reference solutions of tannic acid (20, 40, 60, 80, and 100 µg/mL) were prepared in the same manner as described earlier. The test and standard solutions were measured for absorbance at 700 nm using a UV-visible spectrophotometer, compared to the blank.

Determination of total sugar content

The total soluble sugar content of the selected sample was determined by using the method of (Dubois *et al*., 1956). About 1-mL of sample extract was taken in a test tube combined with 1-mL of 5% phenol solution. Subsequently, 5 mL of 95.5% sulfuric acid was added to the sample. Next, the test tube was incubated for a duration of 10 minutes before being vortexed for a period of 30 seconds. Following this, the test tube was placed in a water bath at ambient temperature for 20 minutes to allow the color to develop. Eventually, the UV-visible spectrophotometer was utilized to measure the absorbance at a wavelength of 480 nm. The total soluble sugar determination standard curve was created with glucose solutions and reported as gm/100 g of sample

Determination of reducing sugar content

The reduced sugar content of the experimented samples was analyzed by the following method suggested by (Miller, 1959). For DNS reagent preparation, 1 g DNS was dissolved in 20 mL 0f 2 M NaOH and then mixed with 30 gm potassium-sodium tartrate dissolved in 50 mL of distilled water. After mixing, the final volume was made up to 100 mL. In a test tube, 0.5 mL of sample extract was mixed with 0.5 mL DNS solution. Then, the mixture was boiled for 10 minutes and cooled by immersing the sample containing the test tube in cold water. After that, 5 mL distilled water was added to the test tube and mixed well. At last, the measurement of absorbance was taken utilizing a UV-visible spectrophotometer at 540 nm wavelength. The standard curve was created using glucose solutions and presented as grams per 100 g of the sample.

Determination of non-reducing sugar content

The non-reducing sugar content of the product samples was determined by subtracting the reduced sugar content from the total soluble sugar content by using the following formula:

Non-reducing sugar (g/100 g) = Total soluble sugar – Reducing sugar content

Antioxidant activity assay (DPPH)

The antioxidant activities of the sample were assessed using 1, 1-diphenyl-2–picrylhydrazyl (DPPH) radical. It is a free radical with a purple color and has a maximum absorption at 517 nm. The free radical scavenging activity is based on the discoloration of the compounds when reduced by a free radical scavenger. About 100 µL of the samples was added to 0.004% DPPH solution which was prepared by dissolving 0.004 g DPPH in 100 mL methanol in a dark colored bottle. Then, the solution was mixed thoroughly and kept in a dark place for 30 minutes at room temperature. After that, the absorbance was read at 517 nm using a UV-visible spectrophotometer. The antioxidant activity of ascorbic acid was also measured as a standard for comparison.

The following formula was used to compute the percentage of antioxidants or RSA:

$$\%DPPH\ radical\ sacvenging = \frac{Ab(control) - Ab(sample)}{Ab(control)} \times 100$$

Ab (control) = absorbance of DPPH alone at 517 nm
Ab (sample) = absorbance of DPPH along with sample extract at 517 nm

FTIR Spectroscopy

Food samples were characterized using an FTIR spectrophotometer (Shimadzu, IRAFFINITY-1S CE) in wave number region 4000 to 400 cm^{-1} for the identification of species and functional groups. In order to record the spectra, the finished food products were mixed with the highly purified KBr powder (Sigma-Aldrich, FTIR grade, ≥99%) in an agate pastel mortar and converted into a pellet form having 10 mm diameter at pressure 4.5 tons using a hydraulic press. About 6 pellets were made of both finished product samples, both finished products after drying and ashing.

Results and Discussion

Sensory analysis

Sensory attributes score for color, aroma, taste, sweetness, texture/mouthfeel and overall acceptance of prepared products was demonstrated in Table 1. The scores were taken from 11 untrained panelists (students) according to a hedonic scale rating (Figure 2).

Physicochemical analysis

Moisture

The moisture content (%) of the prepared products B-I and B-II was 20.88 ± 0.08 and 39.86 ± 0.28, respectively as shown in Table 2. Sample B-II has more moisture content than B-I as B-I is a fruit bar that has been dried in the sun. According to FSSAI, the moisture content in fruit bars should not be more than 20% so the present product (B-I) conforms to that norm. The product B-II, i.e., jelly

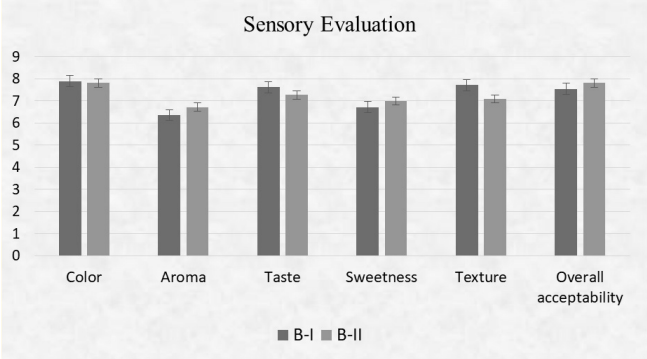

Figure 2: Overall sensory-evaluation values of prepared products

Table 2: Physico-chemical characteristics of the prepared products

Code	*Moisture (%)*	*pH*	*Ash (%)*	*Total soluble solids (%Brix)*	*Titrable acidity (% as citric acid)*
B-I	20.88 ± 0.08	3.74 ± 0.04	0.99 ± 0.06	75.02 ± 0.04	0.62 ± 0.08
B-II	39.86 ± 0.28	4.01 ± 0.01	0.37 ± 0.02	69.10 ± 0.01	0.39 ± 0.03

*The values are mean ± S.D. of three replicates

has a higher moisture content as it has a smooth, gel-like texture. The preservation of the product during storage is strongly correlated with its moisture level, and products with lower moisture content have longer shelf life.

pH

The pH of products B-I and B-II were 3.74 ± 0.04 and 4.01 ± 0.01, respectively, these pH level limits the crystallization of sugars and make it easier for 30 to 50% of the additional sucrose to be inverted during cooking. The pH must not be too low (>3.5) since it may lead to the impairment of sensory qualities such as granular texture, exudation phenomena, excessively acidic flavor, and glucose crystallization (Besbes *et al*., 2009). Maintaining product uniformity, preventing microbiological development, and ensuring optimal pectin gelation are all made possible by precise pH control. By affecting enzymatic and chemical processes, pH influences a product's shelf life, preventing spoiling and preserving quality over time.

Total soluble solids

Sugars make up the majority of total soluble solids (TSS) but minerals and acids also contribute to it. According to FSSAI, fruit bars must contain 75% soluble solids and the total soluble solid content in jelly shall not be less than 65%. The TSS of B-I was 75.02 ± 0.04 and B-II was 69.10 ± 0.01 (Table 2). An increase in TSS implies a decrease in the moisture content of the sample thus increasing the nutritional composition of the jam samples.

Titratable acidity

Table 2 shows the titratable acidity of the prepared products as citric acid percent. One of the many physicochemical factors that affect product quality is titratable acidity; in general, acidity inhibits the growth of microbes. The titratable acidity (%) of products B-I and B-II reported in this study was 0.62 ± 0.08 and 0.39 ± 0.03, respectively. Sample B-1 shows a higher value due to the addition of citric acid whereas product B-II does not contain such an additive. (Brandão *et al*., 2018) Reported that the acidity of jams and jellies should be kept within a range of 0.3 to 0.8%. If this acidity is more than 0.8%, syneresis could happen.

Ash

Ash content was 0.99 ± 0.06 in B-I and 0.37 ± 0.02 in B-II product samples (Table 2). The total ash in the present study is higher than that reported by (Eke-Ejiofor & Owuno, 2013) for jackfruit jam at 0.27%; and higher than those reported by (Mohd Naeem *et al*., 2017) on grape and blueberry jam with content of 0.18 and 0.12%, respectively. The variance in ash concentration, according to (Nwosu *et al*., 2014), is caused by variations in inorganic compounds, particularly the calcium ion found in the pectin that is present in the various fruits. Because mineral components are soluble in water, they undergo significant modifications during cooking processes. By breaking down cell walls, denaturing proteins, and releasing organic acids, cooking may increase the solubility of minerals and increase their bioavailability. Generally, high ash content indicates that the *A. marmelos* products analyzed are a rich source of minerals.

Phytochemical analysis

Qualitative analysis

A. marmelos has been widely utilized in traditional medicinal systems as it has been reported to contain numerous phytochemical compounds such as polyphenol/phenolic compounds, carotenoids, alkaloids, pectin, flavonoids, tannins, coumarins, and terpenoids (Sharma *et al*., 2022). Similarly, certain bioactive compounds from these groups have been isolated and identified in the prepared products. Alkaloids, terpenoids, tannins, flavonoids and phenols were present whereas saponins were absent in both products. Similar results were also reported by (Sharma & Chauhan, 2023) in fruit pulp powder of *A. marmelos* which revealed the existence of tannins, phenols, flavonoids, alkaloids, steroids, and terpenoids but depicted the absence of saponins. These bioactive compounds have numerous health-promoting benefits like antioxidant, antimicrobial and anti-inflammatory properties. Phenols inhibit the formation of free radicals thus exhibiting antioxidant capacity and enhancing the shelf life of food products.

Quantitative analysis

As indicated by Table 3, the extract of B-I has the most significant concentrations of total phenols (287.01 ± 0.04 mg/100 g) and total flavonoids (282.91 ± 0.22 mg/100 g). Tannin content was also higher in B-I (0.87 ± 0.21 mg/100 g). B-II has a slightly lesser content of polyphenols as less pulp content was used to make jelly as compared to fruit bars. According to studies by (Behera & Raj, 2018; Dhanda *et al*., 2020) the total phenolic content of bael fruit pulp was 15.588 and 22.02 mg/g, respectively. These results are higher than the current values. Fruit processing

Table 3: Quantitative phytochemical estimation of prepared products from *A. marmelos*

Code	*Phenol (mg/100 gm)*	*Flavonoid (mg/100 gm)*	*Tannin (mg/100 gm)*	*Total sugar (gm/100 gm)*	*Reducing sugar (gm/100 gm)*	*Non-reducing sugar (gm/100 gm)*
B-I	287.01 ± 0.04	282.91 ± 0.22	0.87 ± 0.21	3.69 ± 0.87	0.77 ± 0.32	2.12 ± 1.16
B-II	173.72 ± 0.04	142.34 ± 0.20	0.49 ± 0.24	6.87 ± 0.79	1.46 ± 0.49	5.41 ± 1.14

*The values are mean ± S.D. of three replicates

may have reduced total phenolics because of alterations in cell structure that made the fruit's phenolic content more susceptible to non-enzymatic oxidation. Phenolics can help improve the overall evaluation and prolong the shelf life by delaying the microbial invasion in some fruit products and preventing the putrefaction of others (Martillanes *et al*., 2017). Similar values of phenols (256.68 ± 4.33 mg/100 g) and flavonoids (79.04 ± 1.80 mg/100 g) were found in the bael jam reported by (Rahman *et al*., 2024).

Sugar content of the prepared products

Reducing sugars and non-reducing di- and oligosaccharides, such as sucrose, which are transformed into reducing sugars by mild acid hydrolysis, are included in total sugars. Strong acids hydrolyze starch to produce glucose. Table 3 shows the total sugar amount of the products, which did not considerably vary. B-I and B-II samples had total sugar contents of 3.69 ± 0.87/100 g and 6.87 ± 0.79 mg/100 g, respectively with outcome study's outcomes, sample B-II had a higher concentration of reducing sugar (1.46 ± 0.49/100 g) than sample B-II (0.77 ± 0.32/100 g). The table showed that samples B-I and B-II had non-reducing sugar contents of 2.12 ± 1.16/100 g and 5.41 ± 1.14/100 g, respectively. The addition of supplied sugar during product processing and the high TSS value were the causes of the high total sugar content for product samples. (Giraldo *et al*., 2003) Reported that during the

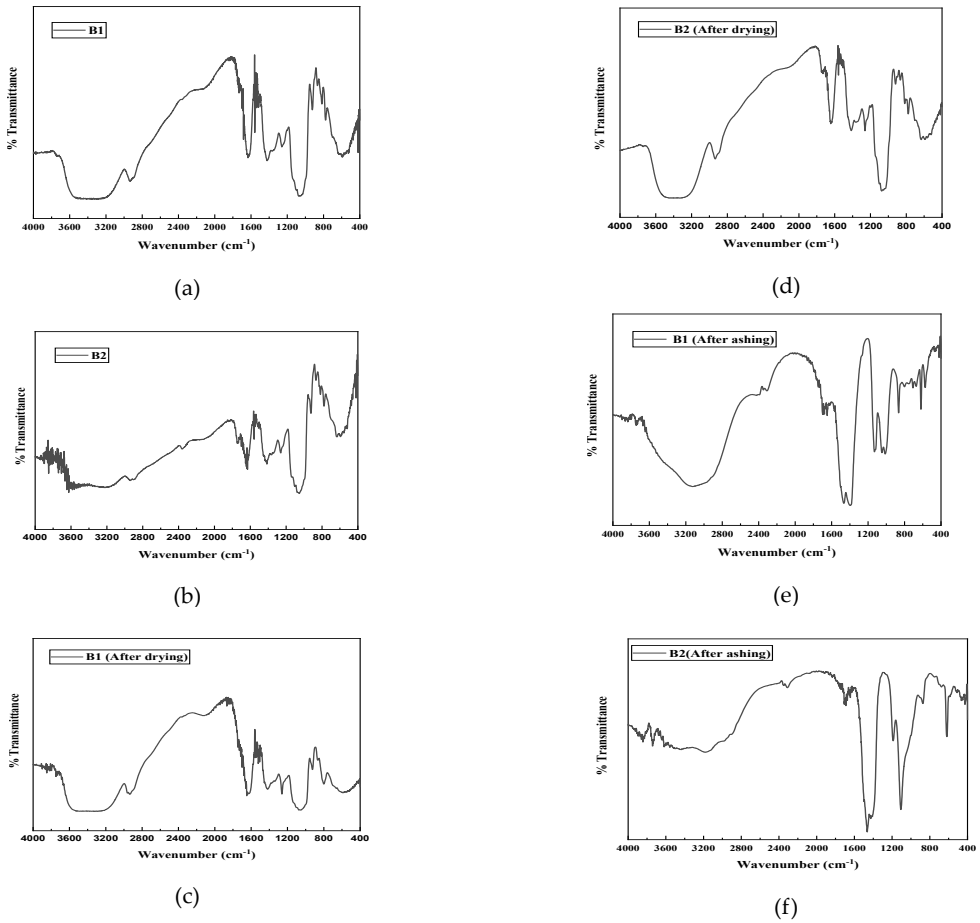

Figure 3: FTIR graphs %Transmittance between wavenumber 4000–400 (cm^{-1}) of B1 and B2 (a, b), after drying of B1 and B2 (c, d), after ashing of B1 and B2 (e, f)

Table 4: Functional groups identified in samples at different wave numbers

Sample	*Functional group at wavenumber (cm^{-1})*
B1	3370: O-H str. (s) of alcohol, 2946: C-H str. (s) of alkane, 1629: C=C str. (m) of alkene, 1420: O-H bend (m) of carboxylic acid, 1253: C-O str. (s), 1065: C-O str. (s)
B2	2946: C-H str. (s) of alkane, 2353: O=C=O str. (s) of carbon dioxide, 1741: C=O str. (s), 1643: C=C str. (w) of alkene, 1420: O-H bend (m) of carboxylic acid, 1260: C-O str. (s), 1065: C-O str. (s)
B1 (after drying)	3384: O-H str. (s) of alcohol, 2932: C-H str. (s) of alkane, 1636: C=C str. (w) of alkene, 1517: N-O str. (s), 1413: O-H bend (m) of carboxylic acid, 1260: C-O str. (s), 1065: C-O str. (s), 926: O-H bend, 870: C-H bend (s)
B2 (after drying)	3398: O-H str. (s) of alcohol, 2932: C-H str. (s) of alkane, 1741: C=O str. (s), 1636: C=C str. (w) of alkene, 1406: O-H bend (m) of carboxylic acid, 1253: C-O str. (s), 1051: C-O str. (s), 926: O-H bend, 856: C-H bend (s)
B1 (after ashing)	3126: O-H str. (w) of alcohol, 1650: C=C str. (w) of alkene, 1469: C-H bend (m) of methylene group, 1392: O-H bend (m) of carboxylic acid, 1134: C-O str. (s), 1051: C-O str. (s), 856: C-H bend (s)
B2 (after ashing)	3168: O-H str. (w) of alcohol, 1691: C=O str. (s) of carboxylic acid, 1462: C-H bend (m) of methylene group, 1197: C-O str. (s), 1100: C-O str. (s), 876: C-H bend (s)

osmotic dehydration process, the sugar content of the mango increased due to a rise in the concentration of the sucrose solution.

Antioxidant assay

The percentage of inhibition in B-I and B-11 was 69.5 ± 11.36 and 54.4 ± 4.59, respectively in methanol-ethanol extract. The values obtained for developed products were lower than the RSA values of standard ascorbic acid (80.8 ± 9.58). This result leads us to say that B-I (bael fruit bar) has a moderate antioxidant activity compared to seabuckthorn jam with a similar percentage of 69.39% (Selvamuthukumaran & Khanum, 2014). A study by (Rahman & Parvin., 2014) showed that, at 5 to 0.15 µ/mL extract concentration, chloroform and aqueous extract of dry and ripe *A. marmelos* fruit exhibit strong free radical quenching activity (lowering ferric chloride), with ranges of 88 to 65%. The studies' conclusions suggested that the phytochemicals found in fruit, including flavonoids, tannins and phenols, may be linked to *A. marmelos*' antioxidant capacity. The aqueous extract of bael fruit pulp from the Chennai area was found to have a maximum DPPH free radical scavenging activity of 60.70% (Sharma *et al*., 2022) which was near to the antioxidant activity of prepared products B-I and B-II in methanol-ethanol extracts. The antioxidant activity of *A. marmelos* suggests that the fruit can be utilized as an additive with other medications to boost their efficacy and as an antioxidant agent to cure cellular damage brought on by free radicals.

FTIR analysis

The analysis of A. marmelos products of various groups by FTIR spectrophotometer provides different specific functional groups in wavenumber region 4000 to 400 cm^{-1} (Figure 3) which reflects the presence of special bioactive compounds in the raw material present in prepared products. The dominant functional groups present in the product are summarized in Table 4. FTIR is a spectroscopic technique that measures the absorption of infrared light by a sample. The peaks in the FTIR spectra correspond to different functional groups in the sample, and their wave numbers indicate the specific vibrations of these functional groups. FTIR results of the sample show the presence of main functional groups, such as alcohols, alkanes, alkynes, amines, carbonyl groups, and carboxylic acids. These functional groups can provide information on the chemical composition and molecular structure of the samples. (Bhardwaj *et al*., 2018) Observed some bands at 1392.65 cm^{-1} in the *A. marmelos* extract due to aromatic ring framework vibration which was also observed in product B-II (after ashing). (Sharma *et al*., 2024) Reported that the bael fruit polysaccharide mainly comprises O-H, C-H, C–O, and C=C as major functional groups which also reflect their presence in the bael fruit bar and jelly. Overall, it can be concluded that different protein and carbohydrate fractions are also included in bael fruit products.

Conclusion

To determine the fruit's potential in the future, the current study aimed to exploit the underutilized fruit *A. marmelos* (Bael). The two products developed from *A. marmelos* were fruit bar and jelly in which fruit bar has higher pulp content than jelly. According to sensory analysis, products were found to be acceptable by the consumers. As a consequence of this investigation, it became clear that bioactive compounds such as total phenol, flavonoid, tannin, and other phytochemicals can be found in significant amounts in prepared products of *A. marmelos* whereas qualitative analysis showed the presence of alkaloids, terpenoids, and tannins. Furthermore, products are a good source of antioxidants, which are particularly effective at stopping detrimental events like the oxidation of lipids brought on by oxidative stress and contain functional groups such as O-H, C-H, C=O, and C=C. The pulp of the fruit has an astringent

taste which could affect the sensory quality of the products so citric acid was added to enhance the taste of the prepared products.

Investigating bael's bioactive compounds, optimal extraction methods, and formulation techniques could lead to innovative products that exploit its nutritive and therapeutic properties.

The prepared product fruit bar has strong commercial potential across several industries. It can be marketed as a convenient, nutritious snack in the packaged foods sector, appealing to busy consumers looking for healthier alternatives as a grab-and-go meal option. Jelly also offers diverse commercial industrial applications. It can be incorporated into the food manufacturing industry as a key ingredient in confectionery products, desserts, and snacks, enhancing flavor and texture. The scalability of these prepared products for industrial applications is highly promising, as they can be produced efficiently in large quantities to meet diverse market demands and are cost-effective with longer shelf life. Additionally, research into sustainable cultivation practices and effective utilization of bael by-products could drive economic growth and environmental sustainability. Hence, the outcome of this research will suggest that further research into bael (*A. marmelos*) is essential for unlocking its full potential in product development.

Authors Contributions

UG: methodology, validation, analysis, investigation, writing—review & editing; NKS: FTIR analysis, determination of ash; VT: Corresponding author, supervision, conceptualization, resources, writing, review and editing.

Conflicts of Interest

The authors declare that they have no conflict of interest.

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