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Utilization of residual bael pulp to prepare nutritionally enhanced cookies

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Abstract

The study aims to demonstrate the nutritional value of residual bael (*Aegle marmelos*) pulp (remaining after juice extraction) and a new application of such an underexplored fruit byproduct as a constituent to enhance the nutritional value of cookies. The residual bael was dried and ground into a powder. Proximate composition, physicochemical properties, and overall bioactive content of the residual pulp powder (RPP) were analyzed. The weight balance of bael fruit was described, with 37.6% peels, 3.4% seeds, and 59% pulp. The moisture content of fresh pulp was 72.9%, and RPP was 12.1%. The RPP was rich in crude fiber (29.9% w/w), total phenolic content (TPC, 37.8 mg GAE/g), antioxidant capacity (AOC, 2.6 mg GAEAC/g), and total carotenoid content (TCC, 0.82 mg BCE/g). Five recipes of cookies were prepared by supplementing with RPP replacing 0–20% of the wheat flour (WF) in the formulation. As RPP content increased, moisture content, ash content, crude fat, crude fiber, total carbohydrate, calorific value, TPC, TCC, and AOC increased. According to the sensory acceptance (with fuzzy solution), the top three recipes were; cookie-3 (10% RPP) < cookie-1 (0% RPP) < cookie-2 (5% RPP). The order of relative importance of sensory attributes reveals taste & texture as most important. With a rise in RPP substitution, the spread ratio of the cookies improved, hardness reduced, and fracturability decreased. Based on maximum nutritional enhancement, sensory scoring, textural acceptance, and optimum amount of RPP replacement was within 5–10% replacement of WF with RPP.

Keywords Byproduct utilization, Residual bael pulp, Supplemented cookies, Fuzzy-assisted sensory analysis, Texture analysis

1 Introduction

Fruit and vegetable wastes produced during the post-processing stage of the food industry remain underutilized in many cases since the necessary processing technologies are not available to effectively value them [1, 2]. The significant quantity of agricultural byproducts is a matter of grave concern as it adds to the problem of food waste, which in turn can exacerbate many environmental and economic difficulties [3, 4]. Food processing wastes have valuable components that can be exploited because of their nutritional and functional features. These compounds include dietary fiber, antioxidants, essential fatty acids, minerals, and antimicrobials [5, 6]. Fruit industries produce more

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leftovers consisting of fruit skin, stone, or seed kernels due to increased fruit product consumption. Fruit pomaces are rich in dietary fibers and bioactive components, which adds functional benefits such as they help lower blood cholesterol, reduce sugar levels, improve cardiovascular health, provide prebiotics and mitigate constipation issues, and impart antioxidant effects (especially by bioactives) [7–9].

Indian bael (*Aegle marmelos*) fruit is a tropical fruit rich in nutrients, including phenolics, carotenoids, alkaloids, flavonoids, tannins, terpenoids, coumarins, and dietary fibers. Ripe bael pulp has a yellow to orange colour and has a sweet aroma [10]. It is known to provide relief from stomach ailments, diarrhoea, cardiovascular diseases, and diabetic issues. Indian production of bael fruit is about 81.9×10^3 tonnes per year [11]. Juices and related products of bael have started entering the Indian market such as bael *sharbat* or juice and squash, etc. The market for bael juice is expected to continue growing. Growing products of bael fruit will lead to the formation of a considerable amount of its byproducts and wastes. A recent study also highlights the prebiotic potential of pectin from bael pulp waste [12], demonstrating its ability to enhance probiotic survivability, encapsulation efficiency, and stability under simulated gastrointestinal conditions. The inclusion of bael-derived pectin has been shown to improve the viability of probiotic strains during gastric and intestinal transit, extend storage stability, and promote synbiotic functionality [13], thereby supporting gut health through its fermentable dietary fiber properties.

Drying tropical fruits greatly extends their shelf life and facilitates commercialization [14]. Reducing water activity to the proper levels enables the conversion of perishable resources into stabilized products, minimizing microbial spoilage and quality degradation brought on by unfavourable metabolic interactions [15]. So, the fruit pomace, which has various health-promoting nutrients and specific organoleptic properties of the original fruit, can be dried and utilized in other food products. Cookies are widely consumed baked products that have a long-lasting shelf life and are enjoyed by many. Given that sugar, oil, and wheat flour are the main constituents in traditional cookies, it may be argued that they are high in carbohydrates. Furthermore, they are relatively low in dietary fiber, vitamins, and minerals that are reduced during wheat flour refining. They are also deficient in antioxidants and bioactive components. According to Dhingra et al. [16], bakery goods, particularly cookies, are considered the most practical and palatable supplement carriers. Numerous researches have been conducted with the aim of partially replacing wheat flour in cookies with fruit byproducts such as guava peel flour [17], pomegranate peel [18], cashew apple & guava residue [19], watermelon rind waste [20], seriguela fruit residue pulp [21], cocoa pod husk [22], grapefruit pomace [23], and pineapple pomace powder [24]. Furthermore, sensory studies are essential for new product development. Accurate and intelligent analysis of the sensory data through fuzzy logic-based decisions can further enhance the reliability of the outcome [25].

The current study aims to evaluate the nutritional value of residual bael pulp (in dried powder form) and select the best formulation for the cookie supplemented with dried residual pulp by replacing a certain proportion of wheat flour. Nutritional and physicochemical properties of the residual pulp powder (RPP) and RPP-supplemented cookies were analysed. Texture analysis and sensory studies of the cookies were performed. Sensory data was processed with the assistance of fuzzy analysis.

2 Materials and methods

2.1 Raw materials and chemicals

The bael fruit (*Aegle marmelos* (L.) Corrêa) was purchased from a local fruit market in Matunga, Mumbai, Maharashtra, India. The study did not involve the collection of wild, endangered, or protected plant species. Since the plant material (bael fruit) was market-purchased, geographical coordinates are not applicable. As part of the previous study, pectinase enzyme (endo-polygalacturonase) from *Aspergillus niger* was procured from TCI (Tokyo, Japan) [26]. Currently, the other ingredients for preparing cookies required wheat flour (WF), grounded sugar, table salt, fat (vegetable fat, *dalda*), GMS (Glycerol monostearate), baking soda ($NaHCO_3$), ammonia soda (NH_4CO_3), corn flour, SMP (skimmed milk powder), invert sugar syrup, lecithin (liquid), vanilla essence (ethyl vanillin), were purchased from the local supermarkets in Matunga (Mumbai). All the chemicals used for analysis were of analytical grade and sourced from SD Fine-Chem and Himedia Pvt. Ltd. (India).

2.2 Preparation of residual pulp powder (RPP) for byproduct utilization

Juice from bael beverage was extracted by liquifying the pulp with pectinase enzyme [26]. The residual bael pulp remaining after extracting juice was collected and dried in a hot air oven at 55 °C for 24 h [27]. The dried residual pulp was powdered in a domestic mixer grinder for 10–12 min. The residual pulp powder was sieved with a mesh size of 1.0 mm to obtain uniform particle size distribution, ensuring better homogeneity in formulation and minimizing coarse texture during product development. Sieved RPP was then stored in an air-tight container until further use. The process has been outlined in Fig. 1.

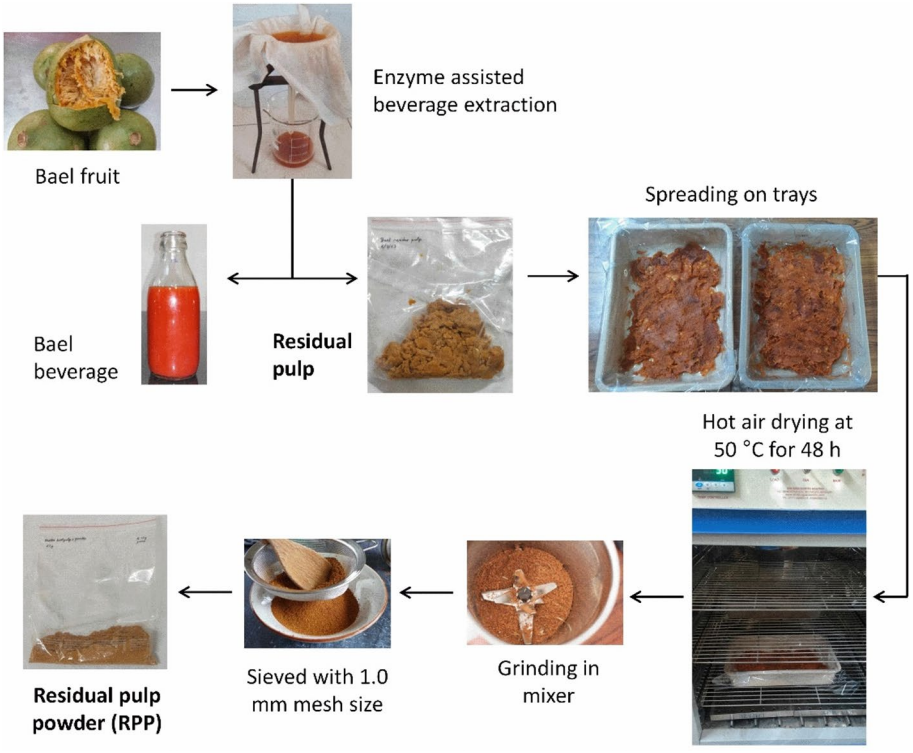


Fig. 1 Steps for preparing residual pulp powder (RPP)

2.3 Development of cookies from RPP

A basic marie-type cookie recipe was followed. The recipe is similar to the recipe suggested by Sykes & Davidson [28], which was modified in the preliminary trials. The ingredients for preparing cookies required wheat flour, RPP, grounded sugar, table salt, vegetable fat (*dalda*), Glycerol monostearate (an emulsifier), baking soda, ammonia soda, corn flour, skimmed milk powder, invert sugar syrup, lecithin (liquid), vanilla essence (ethyl vanillin), and water. Five variations in the recipe were made by replacing 0–20% of the WF (Table 1). First, ground sugar, lecithin, and fat are creamed together for 3 min. Then, the dough with WF and 3/4th of the total water was kneaded for 4 min. In the remaining water, table salt, leavening agents ($NaHCO_3$ & NH_4CO_3), and SMP were dissolved for 3 min and added to the dough. Then, the cream (mixture of sugar, lecithin, and fat) was mixed with the dough and kneaded again for 5 min to ensure uniformity. The kneaded dough was rested for 10 min. After the resting period, the dough was formed into a sheet of ~ 2.5 mm thickness. The sheet was cut into circular pieces, and a thin film of milk was applied. After that, the pieces of raw cookies were put on a metal tray, then placed in a baking oven (electric convection oven / hot air circulating oven) and baked at 160 °C for 25 min. Finally, after baking, the cookies were cooled at room temperature and stored in an air-tight container until further analysis. The steps for preparing cookies have been summarized in Fig. 2.

2.4 Parameters analyzed during byproduct utilization and cookie development

2.4.1 Physicochemical parameter

Colour measurements were conducted following the CIE system, which includes L^* for lightness, a^* for red to green spectrum ('+' indicating red and '-' indicating green), and b^* for yellow to blue spectrum ('+' indicating yellow and '-' indicating blue), utilizing a Hunter colorimeter (LabScan-XE LX17375, USA). The moisture content of the residual bael pulp and the RPP was recorded followed by weight balance from fruit to cookies for estimating yield of RPP. Particle size analysis or sieve analysis of the obtained RPP was performed and calculated as per Eq. 1. Here, D_{sv} = mean surface volume diameter, x_i =

Table 1 Basic cookie recipe with varying proportions of residual pulp powder (RPP) and wheat flour (WF)

S. No.	Ingredients	Quantity				
		Recipe 1	Recipe 2	Recipe 3	Recipe 4	Recipe 5
1	Residual pulp powder (RPP) (g)	0	5	10	15	20
2	Wheat flour (WF) (g)	100	95	90	85	80
3	Corn flour (g)	4	4	4	4	4
4	Grounded sugar (g)	22	22	22	22	22
5	Liquid invert sugar (g)	2.5	2.5	2.5	2.5	2.5
6	Skim milk powder (SMP) (g)	2.7	2.7	2.7	2.7	2.7
7	Vegetable fat (g)	18	18	18	18	18
8	Salt (NaCl) (g)	0.7	0.7	0.7	0.7	0.7
9	Baking powder ($NaHCO_3$) (g)	0.5	0.5	0.5	0.5	0.5
10	NH_4HCO_3 (g)	0.75	0.75	0.75	0.75	0.75
11	Glycerol monostearate (GMS) (g)	0.6	0.6	0.6	0.6	0.6
12	Lecithin (g)	0.6	0.6	0.6	0.6	0.6
13	Flavour (ethyl vanillin) (g)	0.1	0.1	0.1	0.1	0.1
14	Water (mL)	42	42	42	42	42

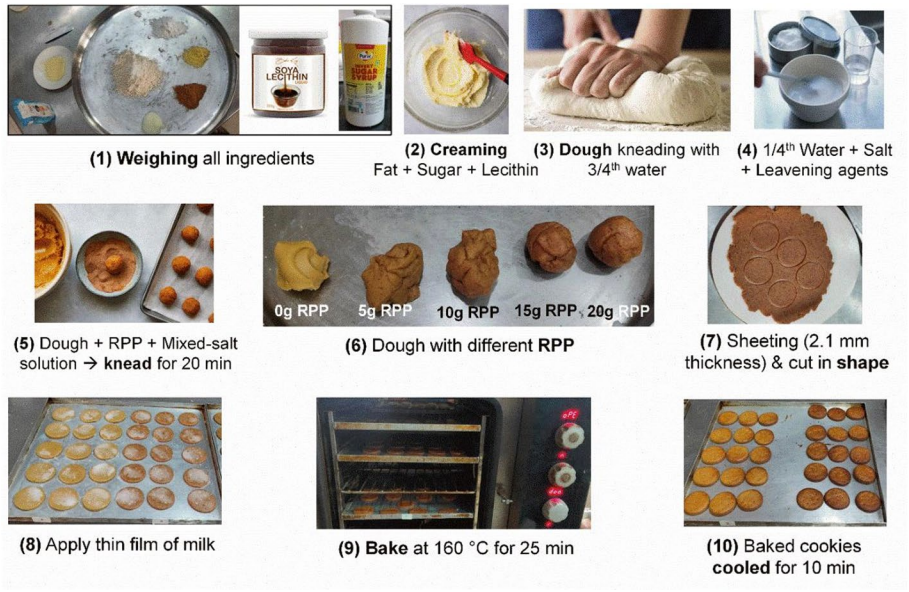


Fig. 2 Stepwise summary of the cookie development process

mass fraction of particles retained in the *i*th sieve, and D_i = mean diameter of particles in the *i*th sieve.

$$D_{sv} = \frac{1}{\sum_{i=1}^{n} \left({}^{x_i}/_{D_i} \right)} \tag{1}$$

The calorie content (theoretical calorific value in kcal/100 g) of all the formulations of the cookies was estimated using Eq. 2. The Proximate composition of the RPP and baked cookies was quantified. Furthermore, physicochemical properties (colour values, spread ratio (*Sr*, Eq. 3) & water activity) [29], texture, bioactive components (total carotenoid content (TCC) & total phenolic content (TPC)), and antioxidant capacity (AOC) were also analyzed.

$$\text{CalorificValue} = (\text{ProteinContent} \times 4) + (\text{FatContent} \times 9) + (\text{CarbohydrateContent} \times 4) \tag{2}$$

$$\text{SpreadRatio}(Sr) = \frac{CookieDiameter}{CookieThickness} \tag{3}$$

2.4.2 Proximate and water activity analysis

The proximate composition (moisture, fat, protein, crude fiber, carbohydrate, and ash) of the RPP and baked cookies are quantified according to the method suggested by Ranganna [30]. Water activity was quantified using a digital water activity meter (Rotronic Switzerland, HC2-a_W) with a 1 g sample load.

2.4.3 Sensory evaluation

A semi-trained panel examined the cookie samples to compare their organoleptic properties.

Sensory evaluation was conducted using 45 semi-trained panellists, which exceeds the minimum recommended number (≥ 30) for acceptability testing to ensure statistical

reliability [31, 32]. The individuals were healthy, nonsmoking who weren't allergic to the bael fruit and were interested in sample tasting were selected. The samples were produced hygienically, and neither their flavour nor fragrance threatened the participants in any way. They had one hour of training every day for five days in span of ten days. The panel members received training on the bael beverage, its processing circumstances, its sensory qualities, and its score sheet. During the training phase, mock evaluation sessions were conducted using reference samples to standardize attribute interpretation and scoring consistency. Panel responses were examined through group discussions and repeat assessments to improve consistency and minimize variability prior to conducting the formal sensory evaluation. They were briefed about the sample, its ingredients, and the preparation process. However, the order of the cookie samples from recipes 1 to 5 was not disclosed during the actual analysis. They were instructed to wash their palates with water between two consecutive sample tastings. The language used to choose terms for the sensory qualities (parameters) was taken from ISO-5492 [33]. The samples were assessed based on five sensory attributes with attribute numbers: (1) appearance, (2) aroma, (3) taste, (4) texture, and (5) aftertaste. A 5-point hedonic scale was employed in place of the traditional 9-point scale to facilitate easier evaluation and ensure greater consistency among semi-trained panel members. Using a shorter scale can reduce the mental effort required during scoring, thereby lowering variability and minimizing response bias, particularly when assessors are not highly experienced [32, 34]. Previous research has indicated that simplified hedonic scales are suitable for acceptability testing and can offer discrimination comparable to longer scales under controlled conditions [35]. Therefore, the 5-point scale was considered appropriate for the present study design and panel composition. Each parameter was scored on a 5-point linguistic scale, with 1 denoting 'poor' and 5 denoting 'excellent'. Panel members evaluated the relative importance (*RI*) of the sensory attributes as well. A comparable scale, ranging from "not at all important = scale-1" to "extremely important = scale-5," was used to rank them. Fuzzy logic was used to process and interpret the sensory data.

2.4.3.1 Fuzzy analysis A modified Mamdani technique and the methodology of Chakraborty et al. [36] and Dhar et al. [37] served as the foundation for the fuzzy algorithm. A summary of the fuzzy method may be seen in Fig. 3. The linguistic score count (*LSC*) and linguistic relative importance count (*LRIC*) were obtained by first gathering the sensory data, then counting the linguistic scores (LS) of the samples and the linguistic relative significance (LRI) of the characteristics. For example, the number of panel members who said that sample 1's appearance was "poor" or the number of candidates who said that the sensory characteristic "aroma" was "very important" were tallied while translating the original linguistic data of LS and LRI, respectively.

A triangular distribution pattern known as the triplet (Fig. 3A) was created by fuzzifying the sensory scores given by the panellists. Equation 4 illustrates how these sensory ratings (*LSC* or *LRIC*) are converted into triplets that correspond to the fuzzified score '$S_k_{attribute-i}$' for the *i*th attribute (there are five sensory attributes) of the cookie made with the *k*th recipe (there are five cookie recipes).

$$S_k_{attribute-i}(a,b,c) = \frac{LSC_{poor}(0,0,25)+LSC_{fair}(25,25,25)+LSC_{good}(50,25,25)+LSC_{very.good}(75,25,25)+LSC_{excellent}(100,25,0)}{LSC_{poor}+LSC_{fair}+LSC_{good}+LSC_{very.good}+LSC_{excellent}} \quad (4)$$

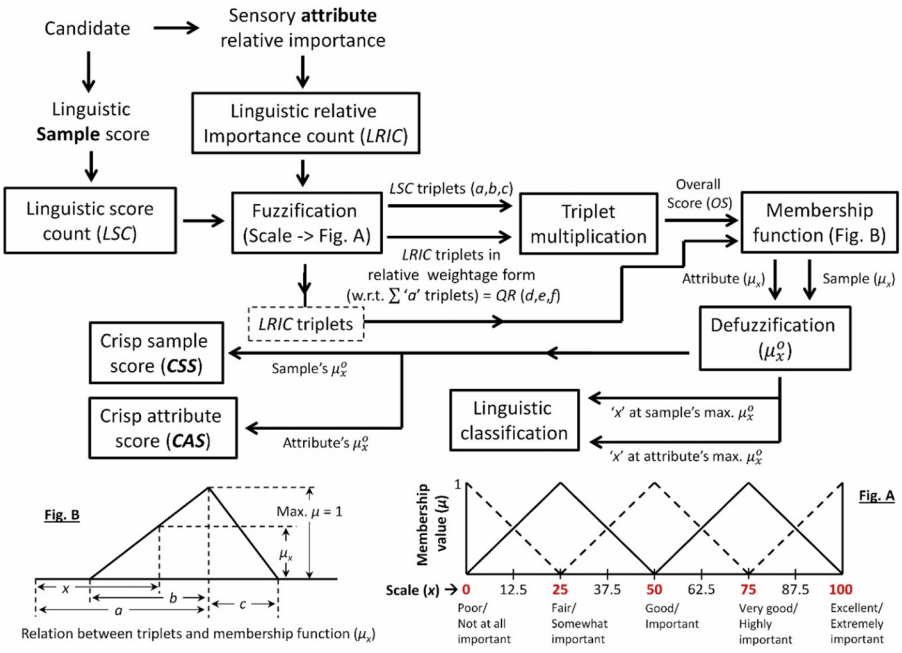


Fig. 3 Flow chart of the sequential calculation steps of fuzzy analysis

The ratio of each triplet to the maximum of the total of the triplet sides was used to determine the triplet of relative weightage (*QR*) for the quality characteristics generally. Equation 5 was used to calculate the *k*th sample's overall sensory score (OS_k).

$$OS_k = \sum_{i=1}^{5} \left(S_k_{attribute-i} \times QR_{attribute-i}\right) \tag{5}$$

Here, '*i*' being 1–5 represents the five sensory attributes: appearance, taste, texture, and aftertaste. A triplet multiplication method (Eq. 6) was used to solve Eq. 5.

$$(a,b,c) \times (d,e,f) = \{(a \times d), (a \times e + d \times b), (a \times f + d \times c)\} \tag{6}$$

The fuzzy scale '*x*' (Fig. 3A), ranging from 0 to 100, represents the linguistic scale from 'poor' to 'excellent' or 'not at all important' to 'extremely important'. Now, it is required to calculate the membership function (μ_x, Eq. 7) that shows how closely each portion of the scale is correlated with the overall score 'OS_k' of the *k*th sample (in triplet form) or relative weightage (QR_i) of an *i*th attribute. Membership function was calculated separately for sample scores (OS_k) and relative attribute scores (QR_i), termed as μ_{Sx} and μ_{Ax}, respectively. Here, parameters *a*, *b*, and *c* represent triplets of OS_k or QR_i.

$$\mu_{Sx} \quad (\text{OR}) \quad \mu_{Ax} = \text{Max}\left[\text{Min}\left\{\frac{x-(a-b)}{b}, \frac{(a+c)-x}{c}\right\}, 0\right] \tag{7}$$

Under the defuzzification step, values of the membership function were converted into the overall membership function (μ_x^o, Eq. 8).

$$\mu_{Sx}^o \quad (\text{OR}) \quad \mu_{Ax}^o = \begin{cases} \mu_0^o = 0.75\mu_x + 0.25\mu_{x+12.5} \\ \mu_{25-75}^o = 0.25\mu_{x-12.5} + 0.50\mu_x + 0.25\mu_{x+12.5} \\ \mu_{100}^o = 0.25\mu_{x-12.5} + 0.75\mu_x \end{cases} \tag{8}$$

Based on the magnitude of the μ_x^o for each of the five major points of '*x*' in Fig. 3A, the linguistic classification of the sample or attribute was performed. For instance, if sample-1 obtained a maximum μ_x^o for $x = 50$, then it can be classified as good. Similarly, if attribute-2 'aroma' obtained maximum μ_x^o for $x = 75$, then it can be identified as highly important. Finally, crisp sample score (*CSS*) and crisp attribute score (*CAS*) were calculated as per Eq. 9 to rank the samples and attributes, respectively.

$$CSS \quad (\text{OR}) \quad CAS = \frac{\sum_{i=0}^{4} (i+1) \cdot \mu_{w_i}^o}{\sum_{i=0}^{4} \mu_{w_i}^o} \tag{9}$$

Here, $w_0 = 0$, $w_1 = 25$, $w_2 = 50$, $w_3 = 75$, and $w_4 = 100$, correspond to the subscripts in $\mu_0^o, \mu_{25}^o, \mu_{50}^o, \mu_{75}^o, \mu_{100}^o$. On a five-point scale, the constant weights in Eq. 9 indicate the scalar interpretation of linguistic scores that range from "1-poor" to "5-excellent" or "1-not all important" to "5-extremely important" for determining *CSS* or *CAS*, respectively.

2.4.4 Texture analysis

A TA.XT*plusC* texture analyser (Stable Micro System, Godalming, U.K.) fitted with a 5-kg load cell and a 3-point bending rig (HDP/3 PB) was used to measure the texture of the cookies. The setup and parameters were fixed according to the method suggested by Milićević et al. [38]. The measurements were performed in compression mode using a cross-head speed of 2.5 mm/s prior to analysis, 2 mm/s during analysis, and 10 mm/s post-analysis. The trigger force was set at 5 g (0.05 N). Cookies' fracturability and hardness were determined by measuring the maximum force and distance at break. Measurements were taken at room temperature (25 °C) 24 h after baking in 6 replicates per batch (or recipe).

2.4.5 Bioactive components and different chemical analyses

The extract for total phenolic content (TPC) and antioxidant capacity (AOC) analysis was prepared using 80% methanol at a 1:10 (w/v) ratio (1 g sample in 10 mL solvent). The mixture was placed in a 15 mL centrifuge tube and agitated on a rocker shaker for 2 h at 25 °C. TPC was determined using the Folin–Ciocalteu colorimetric method [39] with minor modifications. A 5-times diluted (secondary dilution) sample extract was mixed with diluted Folin–Ciocalteu reagent and then 15% (w/v) sodium carbonate solution was added to develop the characteristic blue colour complex. The reaction mixture was mixed with vortex shaker and incubated in the dark at room temperature for 30 min to ensure complete colour development. The reaction mixture was centrifuged at 8000 rpm at 4 °C for 25 min and the absorbance of the supernatant was measured at 735 nm using a UV–Visible spectrophotometer. The results were expressed as milligrams of gallic acid equivalents (GAE) per gram of sample.

The AOC was evaluated using the 1,1-diphenyl-2-picrylhydrazyl (DPPH) radical scavenging assay [39]. A five-fold diluted (secondary dilution) sample extract was mixed with a freshly prepared DPPH working solution, the absorbance of which was adjusted to 1.0 (± 0.02) at 517 nm using the appropriate diluent as a blank. The reaction mixture was incubated in the dark for 30 min to allow interaction between the antioxidants present

in the sample and the DPPH free radicals. The reduction in absorbance was recorded at 517 nm using a spectrophotometer. The antioxidant capacity was expressed as gallic acid equivalent antioxidant capacity (GAEAC).

Total carotenoid content (TCC) was quantified according to the protocol described by Charoensiddhi et al. [40]. Carotenoids were extracted using an organic solvent system consisting of acetone: ethanol (1:1, v/v) supplemented with 0.2 mg/mL butylated hydroxytoluene (BHT). The extraction was performed at a 1:10 (w/v) ratio (1 g sample in 10 mL solvent) in a 15 mL centrifuge tube, which was placed on a rocker shaker for 1 h at 25 °C under reduced light conditions to minimize degradation. The mixture was centrifuged at 8000 rpm at 4 °C for 25 min and the absorbance of the supernatant was directly measured at the 470 nm wavelength using a UV–Visible spectrophotometer. The results were expressed as β-carotene equivalent (BCE) per gram of sample.

2.5 Statistical analysis

All other measurements were performed in triplicates. One-way ANOVA with Tukey's HSD test at a 5% significance level was carried out using SPSS 20.0 (IBM, SPSS Statistics, USA).

3 Results and discussions

3.1 Properties and quality of the residual pulp powder (RPP)

Various quality parameters of the residual pulp powder (RRP) have been studied. The RPP's proximate composition was such that it possesses 12.1% moisture, 10.4% crude fat, 7.7% crude protein, 4.9% ash content, 29.9% crude fiber, and 35% total carbohydrate (Table 2). Additionally, it contained 37.8 mg GAE/g TPC, 0.82 mg BCE/g TCC, 2.6 mg GAEAC/g AOC, and 0.39 g GE/g TRS. It can be observed that RPP is rich in crude fiber and has a good amount of minerals (as per high ash content). Hussain et al. [7] also suggested that the majority of fruit pomace and wastes are rich in crude and dietary fibers. Dietary fibers can help lower blood cholesterol, reduce blood sugar, and act as prebiotics for the probiotic bacteria in our gut [7]. Jose et al. [24] have utilized pineapple pomace

Table 2 Proximate composition, bioactive content, and physicochemical properties of residual pulp powder (RPP)

Category	Parameter	Value
Proximate (% w/w)	Moisture content	12.1 ± 0.3
	Crude fat	10.4 ± 0.1
	Crude protein	7.7 ± 0.2
	Ash content	4.9 ± 0.1
	Crude fiber	29.9 ± 1.2
	Total carbohydrate	35.0 ± 3.3
Physico-chemical	Water activity (a_w)	0.43 ± 0.01
	D_{sv} (μm)	418
	L^*	42.4 ± 0.1
	a^*	15.2 ± 0.2
	b^*	18.8 ± 0.1
Bioactive & bioactivity	TPC (mg GAE/g)	37.8 ± 3.2
	AOC (mg GAEAC/g)	2.6 ± 0.4
	TCC (mg BCE/g)	0.82 ± 0.03
	TRS (g GE/g)	0.39 ± 0.03

Mean surface volume diameter (D_{sv}), total phenolic content (TPC), antioxidant capacity (AOC), total carotenoid content (TCC), and total reducing sugar (TRS)

powder (PPP) to prepare supplemented cookies. The authors observed a proximate composition for PPP to be 3.2% moisture, 5.3% protein, 0.4% fat, 1.8% ash content, 71.3% carbohydrates, and 18.1% dietary fiber content. PPP was rich in carbohydrate and fiber content. However, compared to PPP, RPP contained lower carbohydrate content and higher fiber and ash content, which is advantageous in the current scenario. The TPC and AOC content of RPP was even higher than in the bael beverage (21.8 mg GAE/mL TPC and 0.7 mg GAEAC/mL AOC in the beverage). RPP also contains some minerals in the form of ash content and carotenoids in the form of TCC, which indeed have some health benefits.

Rahman et al. [14] utilized bael powder from fresh bael pulp in their work, some connections can be observed. They stated that in powder of fresh bael pulp, the TPC of 604 mg/100 g existed. The ethanol extracts of powdered fresh pulp had the DPPH-based antioxidant capacity of 1499 μmol/g and the methanol extract exhibited 1400 μmol/g AOC. Subsequently, the total sugar or total carbohydrate of 2.9 g/100 g and 0.32 g/100 g reducing sugar was discovered in powdered fresh bael pulp. In another study, researchers reported the β-carotene content of oven-dried fresh bael pulp as 1.1 mg/100 g [27], which is slightly higher than the TCC observed in the present sample (RPP). Although TCC reflects the total carotenoid content, its lower value in RPP can be attributed to the substantial loss of carotenoids that occurs during juice extraction, as RPP represents the residual waste or by-product left after processing. Apart from this, RPP has a water activity of 0.43, making it a low water activity ($a_w < 0.60$) food ingredient, which potentially allows it to be safe for extended storage. Benefits of low water activity has also been highlighted by Jose et al. [24]. Its colour is brick orange and has colour values of 42.4 L^*, 15.2 a^*, and 18.8 b^*. The mean surface volume diameter (D_{sv}, particle size) of grinded RPP particles was 418 μm. Overall, RPP has excellent potential to be used as a partial flour replacer in cookies and enhance their nutritional profile.

3.2 Weight balance of the materials and yield of residual pulp powder (RPP)

Cookies with five different recipes were prepared by replacing a specific portion of the wheat flour (WF) that specifically included 'WF: RPP' gram proportion of 100:0 g, 95:5 g, 90:10 g, 85:15 g, and 80:20 g, respectively (Table 1). In terms of percentage, RPP content varied from 0 to 12.6% (w/w). The image of the developed cookies is given in Fig. 4 (bottom right).

Increasing the proportion of RPP to more than 20 g in the 194.9 g of total ingredient mass (including water) made the dough difficult to form and harder to knead. The weight balance from the initial bael fruit to cookies is described in Fig. 4. Kaur & Kalia [41] reported that bael fruit was constituted of 24% peel 68% pulp, and 1.3% seed. However, the current bael fruit contains about 37.6% peels, 3.4% seeds, and 59% pulp. Such difference can mostly be due to different fruit variety. About 51.4% of the current fresh bael pulp was liquefied during pulp liquefaction with pectinase enzyme. After the enzyme-assisted extraction of juice from the fruit, the residual pulp was left, which was about 27.7% of the total weight of the initial fruit and 47% of the fresh bael pulp. The process of converting the residual pulp into RPP has been highlighted in Fig. 1. The yield of RPP was 7.8% as per the total fruit and 13.2% as per fresh pulp. From the total weight of the cookie ingredients (194.9 g), each cookie recipe produced 159.1 g of cookies. The

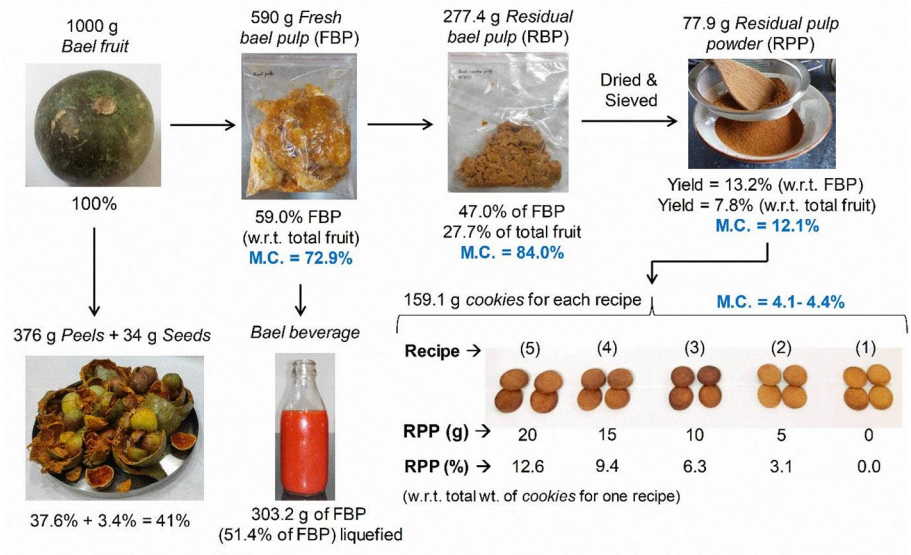


Fig. 4 Overall weight balance and yield of RPP

moisture content (MC) of materials was 72.9% for fresh pulp, 84% for residual pulp, 12.1% for RPP, and 4.1–4.4% for cookies.

3.3 Observing the quality of cookies incorporated with residual pulp powder (RPP)

Numerous quality parameters of the five recipes of cookie were analyzed that included proximate composition, calories (theoretical), bioactive content, antioxidant capacity, physical properties (colour, spread ratio, and texture in terms of hardness & fracturability), and sensory acceptance.

3.3.1 Sensory evaluation

Among all the responses, sensory acceptance is one of the most essential quality parameters for any new food product. The sensory data was processed with fuzzy logic that provides an overall sensory score for samples and a relative importance score for sensory attributes in terms of crisp sample score (*CSS*) and crisp attribute score (*CAS*). The *CSS* values for the five recipes (having different RPP content) of cookies, the *CAS* values of the sensory attributes, and their associated linguistic class are displayed in Fig. 5. Among the five recipes, recipe-2 (WF: RPP = 95:5 g) received a maximum *CSS* of 3.17 and recipe-5 (WF: RPP = 80:20 g) obtained a minimum *CSS* of 2.18. The first three recipes from 1 to 3 were under 'good' linguistic class and '4–5' were under 'fair' linguistic class. The order of cookies of different recipes was cookie-5 < cookie-4 < cookie-3 < cookie-1 < cook ie-2. So, increasing the RPP content to more than 10 g will result in cookies with a lower linguistic class (fair). Perhaps exceeding a specific limit of RPP brings in more roasted bael fruit's aroma and astringent taste that may not be liked by the consumers.

Reduction of sensory acceptance was also observed by Ismail et al. [18] during supplementing cookies with dried pomegranate peel powder (PoP), which imparted off flavour and colour to the cookies when PoP was added to replace about ≥ 6% of wheat flour (WF). Uchoa et al. [19] observed an increase in overall sensory acceptance with the rise in guava fruit powder (replacing 0–20% of WF in cookies) content but noted a decrease in acceptance with the increase in cashew apple fruit powder (replacing 0–20%

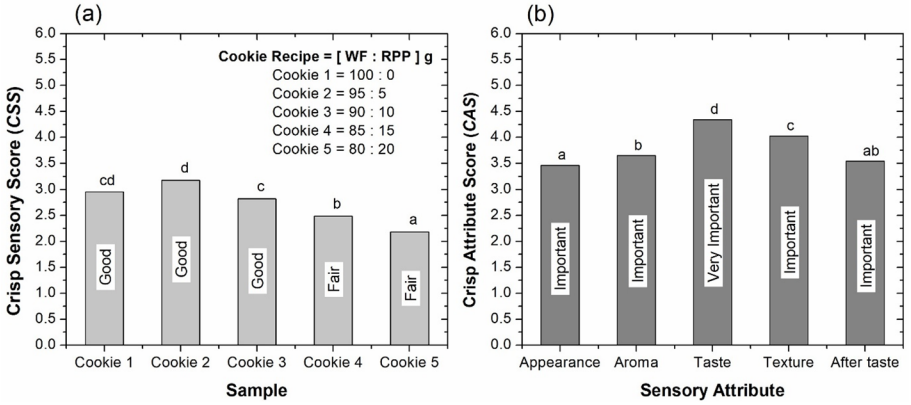


Fig. 5 (**a**) Sensory scores of cookies and (**b**) relative importance scores of the sensory attributes along with their linguistic class. The different alphabets in the column labels represent that the values belong to different subsets at a confidence level of 95%. ABBREVIATIONS: wheat flour (WF) and residual pulp powder (RPP).

of WF in cookies). Rocha Parra et al. [8] evaluated cookies containing 15% apple pomace through a sensory test with untrained panellists using a nine-point hedonic scale. The addition of pomace did not significantly affect appearance, aroma, texture, or overall acceptability. However, it consistently improved taste, irrespective of pomace particle size. When orange peel powder was added to cookies at levels of 5–20%, the scores for colour, appearance, aroma, texture, taste, and overall acceptability slightly decreased, but not significantly [42]. The overall acceptability scores (7.30–8.30) showed that semi-trained panellists still liked the cookies, ranging from 'moderately liked' to 'very much liked.' This indicates that replacing up to 20% of wheat flour with orange peel powder can add functional benefits without negatively affecting sensory quality [42]. In sensory evaluations using a nine-point hedonic scale, trained panellists reported that increasing levels of pomace and kinnow peel caused a significant decline in both flavour and texture scores [43]. Asadi et al. [44] reported that increasing the level of chiku pomace from 0% to 12% led to a gradual decline in the sensory scores for color, taste, aroma, and overall acceptability. Among all formulations, the cookies with 7% chiku pomace achieved the best overall acceptability rating. So, it can be observed that the sensory acceptance can vary based on the type of fruit powder substitution in the WF of cookies.

In the present study, the panellists indicated 'taste' as the most essential sensory attribute and 'appearance' as the least important attribute for cookies. So, the order of relative importance of the sensory attributes was appearance < aftertaste < aroma < texture < taste. In addition to the sensory acceptance score (*CSS*), all the other responses and parameters are summarized in Table 3.

3.3.2 Proximate, bioactive components, and bioactivity

All the parameters are significantly ($p < 0.05$) affected by replacing a small proportion of WF with RPP. As we increase RPP content from 0 to 20 g for recipe-1 to recipe-5, (a) moisture content (MC) reduces (less moisture indicates more storage stability), (b) ash content (mineral content) increases because of higher ash content of RPP than WF, (c) crude protein decreases due to decreasing WF having higher protein than RPP, (d) crude fat increases due to rise in RPP that has higher fat than WF, (e) crude fiber increases because RPP is higher in fiber content than WF, (f) total carbohydrate decreases as RPP has lower total carbohydrate than WF, (g) calorific value, decreases because RPP

Table 3 Nutrients and properties of the RPP-supplemented cookies

Parameter	Recipe no. → [WF : RPP] g →	1 100 : 0	2 95 : 5	3 90 : 10	4 85 : 15	5 80 : 20
Proximate	Moisture	4.37^{b}	4.31^{b}	4.24^{ab}	4.16^{ab}	4.07^{a}
% (w/w)	Ash	2.34^{a}	2.48^{ab}	2.62^{bc}	2.76^{cd}	2.91^{d}
	Crude protein	8.96^{b}	8.87^{ab}	8.78^{ab}	8.69^{a}	8.61^{a}
	Crude fat	14.4^{a}	14.7^{ab}	15.0^{abc}	15.3^{bc}	15.6^{c}
	Crude fiber	1.63^{a}	2.60^{b}	3.58^{c}	4.56^{d}	5.54^{e}
	Total carbohydrate	68.3^{a}	67.0^{bc}	65.8^{abc}	64.5^{ab}	63.2^{a}
Calories	(kcal/100 g)	4.39^{b}	4.36^{ab}	4.33^{ab}	4.31^{ab}	4.28^{a}
Bioactive &	TPC (mg GAE/g)	0.72^{a}	1.58^{b}	2.68^{c}	3.06^{d}	3.52^{e}
Bioactivity	TCC (mg BCE/g)	0.10^{a}	0.19^{b}	0.36^{c}	0.45^{d}	0.54^{e}
	AOC (mg GAEAC/g)	0.06^{a}	0.11^{b}	0.24^{c}	0.33^{d}	0.47^{e}
Physical	*L**	46.1^{e}	41.9^{d}	35.6^{c}	33.1^{b}	30.4^{a}
	*a**	11.1^{a}	12.1^{b}	12.3^{b}	12.9^{c}	13.0^{c}
	*b**	19.6^{e}	17.6^{d}	15.8^{c}	14.9^{b}	13.1^{a}
	Spread ratio (*Sr*)	5.10^{a}	5.21^{a}	5.94^{b}	6.23^{b}	6.79^{c}
Texture	Hardness (N)	54.8^{e}	45.8^{d}	39.9^{c}	34.2^{b}	29.8^{a}
	Fracturability (mm)	0.55^{a}	0.66^{b}	0.79^{c}	0.99^{d}	1.17^{e}
Sensory	*CSS* (out of 5)	2.95^{cd}	3.17^{d}	2.82^{c}	2.48^{b}	2.18^{a}

The different alphabets in superscript within a row represent that the values belong to different subsets at a confidence level of 95%. ABBREVIATIONS: residual pulp powder (RPP), wheat flour (WF), total phenolic content (TPC), total carotenoid content, antioxidant capacity (AOC), and crisp sample score (*CSS*)

contains more fiber and relatively lower carbohydrate than WF, and (h) TPC, TCC, & AOC increases due incorporation of nutrient-rich RPP.

The RPP contains 7.7% crude protein; thus, incorporation of 10 g RPP contributes approximately 0.77 g protein to the formulation. Although this is lower than the protein contribution from wheat flour (WF), RPP still provides a modest amount of plant protein along with significantly higher dietary fiber and bioactive compounds. Therefore, the substitution primarily enhances functional properties rather than protein enrichment. Although incorporation of RPP significantly increased TPC, TCC, and antioxidant capacity, the present study did not assess its bioavailability. Further studies using in vitro digestion models are required to confirm physiological availability of these bioactives. Compared to the reference cookie (100% WF, cookie-1), incorporation of RPP resulted in substantial improvements in dietary fiber and bioactive components. Crude fiber increased from 1.63% in the control to 2.60% (5% RPP) and 3.58% (10% RPP), representing approximately 59% and 120% increases, respectively. This enhancement was statistically significant ($p < 0.05$), indicating that even low substitution levels meaningfully improved fiber enrichment.

Total phenolic content (TPC) increased from 0.72 mg GAE/g in the control to 1.58 mg GAE/g (≈ 119% increase) at 5% substitution and 2.68 mg GAE/g (≈ 272% increase) at 10% substitution. Antioxidant capacity (AOC) exhibited a nearly fourfold increase at 10% substitution (0.24 mg GAEAC/g) compared to the control (0.06 mg GAEAC/g). Total carotenoid content (TCC) also increased progressively by 260%, with 10% RPP showing more than threefold elevation relative to the reference cookie. Even though incorporation of RPP significantly enhanced TPC, TCC, and antioxidant capacity, the potential impact of baking temperature on the stability of these bioactive compounds must be considered. Baking at elevated temperatures (typically 160–190 °C) may cause partial degradation of heat-sensitive compounds such as carotenoids and certain phenolics, are particularly susceptible to oxidative and thermal breakdown during processing

[45, 46]. However, thermal processing can also increase the extractability of bound phenolic compounds by disrupting the plant cell matrix, thereby enhancing quantifiable phenolic content [47]. In addition, Maillard reaction products formed during baking have been described to exhibit antioxidant activity and may contribute to the total antioxidant capacity of baked products [48]. Therefore, the overall antioxidant potential observed in RPP-supplemented cookies likely represents a balance between thermal degradation of native bioactives and the formation or improved release of antioxidant-active compounds during baking.

Ismail et al. [18] also improved the nutritional profile (mineral content, TPC, & AOC) of cookies by replacing 1.5–7.5% of WF with pomegranate peel powder. The authors reported that supplementing cookies with PoP (pomegranate peel) led to a significant increase in their dietary fiber content (from 0.32 to 1.96 g/100 g), total phenolics (from 90.7 to 161.9 mg GAE/100 g), and ash content (from 0.53 to 0.76 g/100 g). A similar significant rise was also observed in the levels of essential minerals such as calcium (Ca), potassium (K), iron (Fe), and zinc (Zn) in the cookies supplemented with PoP. The cookies supplemented with kinnow peel and pomace also showed a significant rise in antioxidant activity (DPPH and FRAP) [43]. Cookies enriched with kinnow peel alone had the highest levels of phenolics (12 mg GAE/g), flavonoids (0.47 mg QE/g), and carotenoids (0.76 mg/100 g), followed by those containing both peel and pomace. Rani et al. [42] found that biscuits made with orange peel powder (up to 20% of the mixture) had significantly higher ($p \leq 0.05$) levels of total, insoluble, and soluble dietary fiber, as well as higher total polyphenols and antioxidant activity compared to the control biscuits. The fiber content in the supplemented biscuits ranged from 8.33 to 13.33% (total fiber), 5.43–7.36% (insoluble fiber), and 2.82–6.00% (soluble fiber), while the control biscuits contained only 2.70%, 1.74%, and 0.95%, respectively. Asadi et al. [44] evaluated cookies enriched with dried, powdered chiku (*Manilkara zapota* L.) pomace. Adding chiku pomace significantly increased the cookies' ascorbic acid content and antioxidant activity (measured using DPPH). The radical scavenging activity rose with higher pomace levels, ranging from 5.94% at 4.5% pomace to 7.13% at 12%, compared to only 0.27% in the control. Enriched cookies also showed increased crude fiber, total dietary fiber (both soluble and insoluble), total protein, total fat, energy content, and total phenolics. Likewise, improved AOC of cookies supplemented with pineapple pomace powder [24] and enhanced TPC & AOC of cookies supplemented with watermelon rind powder [20] were recorded in other studies. When RPP content increased over 10 g (> 6.3% of the total weight of ingredients or 10% substitution of WF), sensory and textural quality declined, while nutritional and physical qualities improved and calorific value continued to fall.

It is important to note that the first three recipes from cookie-1 to cookie-3 were under 'good' linguistic class having *CSS* (crisp sensory score) with ≥ 2.82. Even though cookie-2 with 5% RPP replacement showed best results, 10% RPP still showed good sensory acceptability, which is not significantly different ($p > 0.05$) from reference cookie-1 (100% WF) (Table 3). So, statistically, both 5% and 10% RPP formulations were significantly superior ($p < 0.05$) to the control in terms of fiber content and all measured bioactive parameters. However, the magnitude of improvement was more pronounced at 10% substitution. Importantly, while higher substitution levels (15–20%) further enhanced bioactive content, sensory scores declined (up to 'fair' linguistic class) significantly

beyond 10% substitution. Therefore, the 5% and particularly 10% RPP formulations represent a balanced improvement in functional properties without severe compromise in sensory acceptability.

3.3.3 Colour and spread ratio

One of the first things customers notice about the cookies is their colour, which influences their approval of the product. A rise in the RPP content in cookie formulation made the baked cookies darker in shade (as per decreasing L^* or lightness), more red (as per rising + a^*), and less yellow complexion (as per declining + b^*) in colour. In addition to the intrinsic colour of RPP, non-enzymatic browning reactions during baking may have contributed to colour development. The Maillard reaction involves interactions between reducing sugars and amino groups during heating and may begin at temperatures around 110–120 °C, becoming more pronounced above 140 °C, especially under the low-moisture conditions typical of cookie baking [46, 48]. This process results in the formation of brown, high-molecular-weight compounds known as melanoidins, which contribute to reductions in lightness (L^*) and increases in redness (+ a^*). In contrast, caramelization refers to the thermal decomposition of sugars in the absence of amino compounds that generally occurs at temperatures exceeding 150–160 °C, depending on the type of sugar present, and also results in the formation of brown-coloured compounds [49]. Both Maillard reaction and caramelization contributed towards the non-enzymatic browning of cookies, which is somewhat desirable in the current scenario. Since cookies were baked at 160 °C temperature, Maillard reaction is more likely to contribute towards the observed colour changes at higher RPP incorporation levels. However, specific browning intermediates were not quantified in this study. In support of this trend, a rise in browning has also been observed in cookies with an increased amount of watermelon rind powder [20]. In the current scenario, the darker complexion of the cookies might contribute to the reduced sensory acceptance (*CSS*) compared to cookies with ≤ 10% RPP replacement of WF. In another study, addition of apple pomace to the cookie resulted in decrease lightness (L^*), and increased in redness (+ a^*) and yellowness (+ b^*) [8] because of the brown colour of the apple pomace, which again can be related to the partial caramelization of apple sugar during the initial drying process. Likewise, Asadi et al. [44] noted a decrease in L^*, increase in a^* and b^* value in cookies supplemented with concentrated Chiku fiber powder (Chiku pomace). However, Yaqoob et al. [43] discovered that adding kinnow peel and pomace to cookies increased their L^*-*value*, which may be attributed to the light colour of the peel & pomace.

Spread ratio (*Sr*) is an important parameter reflecting the quality of the cookies. Mathematically, *Sr* will decrease with the increasing thickness of the baked cookies but rise with the expanding diameter. Higher *Sr* is desirable for good quality cookies [50]. The *Sr*-value greatly depends on the dough viscosity and water absorption capacity of the flour mix [20]. So, with increasing supplementation with RPP in the formulation, the water absorption capacity of the flour mix (WF + RPP) reduced and decreased the dough viscosity, causing the *Sr*-values to rise. In the case of the present sample, *Sr* improved with a rise in RPP substitution, which was advantageous. For a similar reason, the *Sr* of cookies increased with the addition of pineapple pomace powder [24]. Naknaen et al. [20] also reported that the *Sr*-value improved with increasing the ingredient content of high-maize-starch as dough viscosity got reduced (associated with reduced water absorption

capacity of the dough). Still, the *Sr*-value dropped with the addition of watermelon rind powder (WRP) for cookies prepared by substituting WF due to an increase in dough viscosity (associated with increased water absorption capacity of the dough). Yaqoob et al. [43] observed a decreased in the *Sr*-value due to decrease in cookie diameter. However, no significant change in spread ration of control cookies and cookies added with chiku pomace was noted by Asadi et al. [44].

3.3.4 Texture

The texture of cookies is one of the main elements that affect their eating quality. When cookie dough was baked, a cellular solid with a porous interior structure and a thin coloured surface developed, which reduced the product's bulk density. This was significantly ($p < 0.05$) impacted when the RPP replaced a small portion of WF in the cookie. The texture of the baked cookies was analyzed in terms of hardness (N) and fracturability (mm). The hardness of a cookie represents the first biting force required to break it with molar teethes or resistance to bending/snapping, and it stands for adjectives like soft to hard [38]. Moreover, fracturability represents the distance the teeth need to go into the cookie to reach the point of breakage or fracture, and it stands for adjectives like crumbly to brittle [50]. Ideally, a cookie should be less hard (but not too soft to make it fragile), easy to break with teeth, and somewhat crumbly in nature but not brittle, which will make it more delicate and vulnerable to breakage [50, 51]. Compared to the reference cookie (100% WF), incorporation of RPP significantly modified textural parameters ($p < 0.05$). Hardness decreased progressively from 54.8 N (control) to 45.8 N (5% RPP) and 39.9 N (10% RPP), representing approximately 16% and 27% reductions, respectively (Table 3). This reduction indicates a softer bite, which may enhance ease of mastication without compromising structural integrity. At the same time, fracturability increased from 0.55 mm (control) to 0.66 mm (5%) and 0.79 mm (10%), suggesting improved crispness and desirable crumbly characteristics. These changes can be attributed to the dilution of gluten-forming proteins and the increased fiber content from RPP, which disrupts the continuous gluten matrix and promotes a more porous structure. Similar structural modifications have been reported when fiber-rich ingredients are incorporated into wheat-based bakery products, where weakening of the gluten matrix leads to reduced hardness and increased fracturability [16, 52].

On the other hand, further substitution (15–20%) led to excessive softening (29.8 N) and higher fracturability (1.17 mm), resulting in overly soft and brittle cookies with reduced sensory scores. Maximum RPP addition of 20% (recipe-4) caused the baked cookies to obtained minimum *CSS*. Thus, although higher RPP levels enhanced nutritional and bioactive properties, the 5–10% substitution range provided a balanced improvement by significantly increasing functional components while maintaining acceptable texture and sensory quality. Naknaen et al. [20] reported that the hardness of baked cookies decreased from 687 N for 'control' to 517 N for '30% WRP replacement', increasing substitution of WF with hi-maize starch and WRP, separately. Similarly, Asadi et al. [44] noted a decrease in hardness with addition of chiku pomace; hardness in control cookie (without chiku pomace) was 2266 g and it decrease from 1840 g to 1383 g for respective chiku pomace of 4.5% to 12%. In another literature, the authors discovered that with increasing content of 'pineapple pomace powder' from 5 to 15% substitution of WF, the texture of cookies became less hard with no significant change in fracturability

[24]. Janotková et al. [53] also discovered a decline in the cookie's hardness but observed an insignificant (p-value > 0.5) reduction in its brittleness in cookies incorporated with sea buckthorn biomass (5–20%) compared to the control. Authors attributed such results to the progressive decrease in gluten content, which weakens gluten network formation, along with increased competition between sugar and flour for available water. The trend observed for change in hardness was similar to the current situation, but the trend for fracturability was different, probably due to different WF replacers and their interaction with dough ingredients.

Nutritional and physical properties improved, and calorific value continued to decrease with increasing RPP content, but the sensory and textural quality declined with a rise in RPP beyond 10% RPP replacement. Therefore, based on sensory acceptance and texture parameters (suitable hardness and fracturability), RPP content of 5–10% RPP substitution (3.1–6.3% of total ingredient weight) can be considered as the best formulations (recipe 2nd & 3rd) for developing RPP supplemented cookies.

4 Conclusions

The residual pulp (byproduct) remaining after enzyme-assisted pulp liquefaction of bael fruit has good potential to be used in cookie preparation. The residual pulp was dried and grinded to form residual pulp powder (RPP) that was used to replace WF in cookies and enhance its nutritional profile. RPP was rich in crude fiber (35% proximate composition), which can help lower blood cholesterol and act as a prebiotic for gut bacteria. It also contains carotenoids, minerals in the form of ash content, and has a low water activity (a_w < 0.60), allowing it to be shelf stable. The colour of RPP is brick orange, and its surface volume diameter (D_{SV}) is 418 µm. Five cookie recipes with 0–20% substitution of WF with RPP were explored. According to the sensory acceptance (with fuzzy solution), the cookies made with recipe-2 (5% RPP) and recipe-3 (10% RPP) were in the linguistic class of 'good'. Taste and texture were the most essential sensory parameters for the sensory evaluation of cookies. A small proportion of 5–20% WF substitution with nutrient-rich RPP significantly improved the nutritional quality of the cookies in terms of enhanced quantity of fiber, mineral, AOC, TPC, and TCC. The rise in RPP content also results in a darker appearance of the cookies. As RPP was added, the spread ratio of baked cookies improved, hardness diminished, and fracturability increased. The texture was organoleptically acceptable, with up to 10% RPP replacement. So, the nutritional and physical properties improved with increasing RPP content, but sensory and textural quality declined with RPP content beyond 10% RPP substitution. Therefore, 5–10% RPP substitution improves nutritional and bioactive properties without severely compromising texture. Although the developed RPP-enriched cookies demonstrated improved nutritional and bioactive profiles, considering the limitations of the current study, further investigations on storage stability, microbial status, glycaemic index, in-vitro bioavailability tests, and optimizing baking conditions to maximize retention of thermolabile compounds are necessary to fully establish their functional efficacy and commercial feasibility.

Author contributions

Rishab Dhar: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Resources, Software, Validation, Visualization, Writing – original draft, Writing – review & editing. Snehasis Chakraborty: Conceptualization, Funding acquisition, Project administration, Supervision, Visualization, Writing – review & editing. Ashish Todkar: Data curation, Validation, Writing – review & editing.

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Data availability
The data that support the findings of this study are available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate
Suitable protocols safeguarding the well-being, rights and privacy of participants were followed during the sensory evaluation. The protocol was approved by the Institutional Review Board of the Institute of Chemical Technology (Mumbai) in accordance with the guidelines and regulations of Bureau of Indian Standards. Key measures included voluntary participation without coercion, disclosure of complete information on study procedures, objectives, and potential risks, obtaining informed consent, protecting participant data from unauthorized disclosure, and allowing withdrawal at any point. The participants were duly informed about the objectives of the study, raw materials, procedures involved, possible risks and benefits, as well as their right to withdraw from the study at any stage. Written informed consent was obtained from all participants prior to conducting the sensory evaluation. The plant material, bael fruit obtained from the *Aegle marmelos* tree used in this study was procured from a local market in accordance with local regulations. The study did not involve wild or protected plant species, and therefore no specific permissions or licences were required.

Consent for publication
Not applicable. This study does not include any identifiable data from human participants.

Permissions to collect plant material
The plant material (bael fruit) used in this study was purchased from a local market in compliance with local regulations. No wild collection was performed, and as such, no permits or licences were required.

Competing interests
The authors declare no competing interests.

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