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Investigating the physicochemical characteristics and sensory analysis of kaya formulations enhanced with jackfruit (Artocarpus heterophyllus)

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ABSTRACT

This study evaluated the potential of jackfruit pulp as a functional ingredient in kaya, aiming to enhance nutritional quality while reducing fruit spoilage. Proximate analysis showed that jackfruit kaya contained adequate protein (3.50–4.80%), fiber (1–2%), carbohydrates (54.80–61%), pH (3.55–4.44), TSS (55–68 °Brix), titratable acidity (0.33–0.38%), and β-carotene (1.25–2.57 mg/g). Color parameters (L*, a*, b*, chroma, and hue) ranged from 31.8–44.51, 9.95–19.13, 15.96–26.95, 23.67–28.72, and 39.35–82, confirming good visual attributes. Sensory evaluation indicated that kaya with 20% jackfruit (F3) received the highest scores for texture (7.13), taste (6.68), and overall acceptability (7.25), with no adverse effect on color or texture. These findings suggest that jackfruit kaya offers a nutritious, palatable, and shelf-stable alternative to traditional formulations, supporting both consumer health and sustainable utilization of seasonal fruits.

1- Introduction

Coconut jam, commonly known as "kaya," is a popular spread in many Asian countries, often enjoyed with breads, pastries, and desserts. Traditionally, kaya is made by cooking a mixture of coconut milk, eggs, and sugar, with pandan leaves (Pandanus amaryllifolius Roxb) imparting its distinctive aroma and green hue [1–2]. The characteristic fragrance is largely attributed to 2-acetyl-1-pyrroline (2AP), a volatile compound unique to the Pandanus genus. Kaya provides a rich source of macronutrients, including proteins, carbohydrates, and fats, contributing to both its flavor and nutritional value [3]. Prior studies have demonstrated the importance of kaya as a supplementary food, particularly in protein- and energy-deficient populations, where its balanced composition can enhance nutritional intake [4].

Jackfruit (Artocarpus heterophyllus Lam.) is a nutrient-dense tropical fruit widely cultivated in Bangladesh, valued for its sweet taste, high fiber content, and bioactive compounds such as lignans, isoflavones, saponins, and antioxidants [5–8]. Despite its health benefits, jackfruit is highly perishable, leading to post-harvest losses estimated at 30–40% [9]. To mitigate these losses and improve year-round availability, there is a growing interest in processing jackfruit into value-added products, including jams, fruit bars, baked goods, and other spreads [10]. While jackfruit has been explored in some processed foods, there is limited research on its application as a primary ingredient in kaya, leaving a gap in understanding its impact on physicochemical, sensory, and microbial quality.

Previous efforts to enhance the nutritional and functional properties of spreads have explored substitutions with fruit pulps and hydrocolloids to improve viscosity, texture, and color [11–13]. However, most studies have focused on conventional spreads, with little attention to developing a jackfruit-based kaya that can simultaneously provide desirable sensory qualities, nutritional benefits, and microbial stability. Additionally, the interactions between sugar, acid, and pectin in this novel formulation remain underexplored, particularly concerning gel formation, texture, and shelf life. Addressing these gaps is crucial to ensure that jackfruit-based kaya meets consumer expectations for flavor, appearance, and consistency.

This study aims to develop a jackfruit-enriched kaya by replacing pandan leaves with jackfruit and to systematically evaluate its physicochemical, microbiological, and sensory properties. The research investigates the influence of jackfruit concentration on color, texture, viscosity, and nutrient composition, while also assessing microbial safety and shelf-life stability. By transforming seasonal jackfruit into a value-added, shelf-stable spread, this study not only addresses post-harvest losses but also provides an innovative, nutritious, and commercially viable alternative to traditional pandan-flavored kaya.

2-Materials and Methods

Raw Materials

Fresh, disease-free pandan leaves and mature jackfruits were collected from the botanical garden of Daffodil International University, Bangladesh. Refined sugar (Meghna Refinery Sugar Ltd.), mature coconuts, and fresh whole eggs were sourced from the local market in Savar, Bangladesh.

Preparation of kaya

The control formulation (F1, Sri-kaya pandan) was prepared using pandan leaf extract, coconut milk, egg, and caramelized sugar. Two experimental formulations were prepared by replacing pandan extract with 10% (F2) and 20% (F3) jackfruit pulp. Jackfruit pulp was manually separated, deseeded, and blended without water using an electric blender (Philips HR2222/00, Netherlands). Pandan leaves were washed, cut, blended with 50 mL water per 100 g leaves using a laboratory blender (Waring 8011S, USA), filtered through a muslin cloth, and the extract collected. Caramel was prepared by heating sugar (20%) at 120–125 °C for 6–8 min on a digital hot plate (IKA C-MAG HS 7, Germany) until golden brown, cooled, diluted with water, and reheated. Eggs were separated, chalazae removed, and yolks whisked using a hand mixer (Kenwood HM330, UK); 20g whisked egg was incorporated. Coconut milk (20%), blended jackfruit pulp (for F2 and F3), and the remaining sugar were added to the caramel mixture. The formulations were cooked in a double boiler (Memmert WNB14, Germany) at 90–95 °C for 12–15 min with continuous stirring using a magnetic stirrer (Heidolph MR Hei-Standard, Germany) until a thick, uniform texture was achieved. The total soluble solids (°Brix) of the formulations were measured as 60, 63, and 55 for F1, F2, and F3, respectively, using a handheld refractometer (Atago PAL-1, Japan).

Table 1: Formulation of Kaya

Raw materials	F1	F2	F3
Egg (%)	20	20	20
Sugar (%)	20	20	15
Coconut milk (%)	20	20	20
Caramel sugar (%)	30	30	25
Pandan leaf (%)	10	-	-
Jackfruit (%)	-	10	20

Here, F1- Pandan leaf incorporated Kaya, F2- 10% jackfruit-based kaya and F3- 20% jackfruit- based kaya

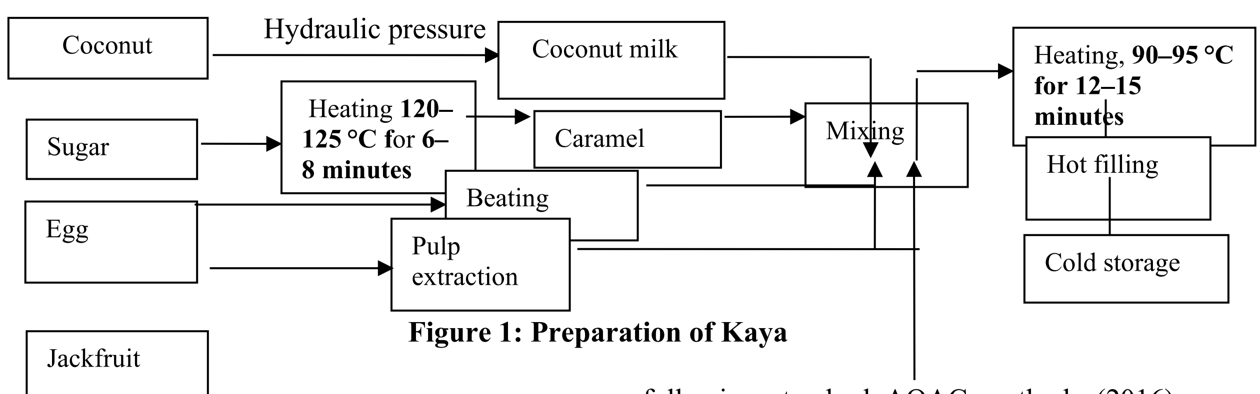

Figure 1: Preparation of Kaya

Determination of Nutritional Compositions

Proximate Composition Analysis

The proximate composition of kaya samples, including moisture, ash, protein, fat, crude fiber, and carbohydrate, was determined following standard AOAC methods (2016). Moisture content was determined by oven-drying 5.0 g of sample at 105 °C for 24 h or until constant weight. The oven used was a drying oven (Memmert Model ED 56, Tuttlingen, Germany). Results were expressed as percentage weight loss relative to the initial sample. Ash content was measured by incinerating dried samples in a muffle furnace (Carbolite CWF 1200, UK) at 550 °C until a constant weight was obtained. Ash percentage was calculated as the ratio of ash weight to initial sample weight. Fat was extracted from 3.0 g of sample using 175 mL of petroleum ether in a Soxhlet extraction unit (Buchi B-811, Switzerland) at 80 °C for 6 h. Fat percentage was calculated as the ratio of extracted fat weight to sample weight. Protein was determined by the Kjeldahl method. Samples were digested with 25 mL concentrated H_2SO_4 at 350 °C for 3 h using a digestion unit (Gerhardt Kjeldatherm KB, Germany). Distillation was performed with 300 mL distilled water, 125 mL NaOH (40% w/v), and 25 mL boric acid solution (4% w/v) using a Kjeldahl distillation unit (Gerhardt Vapodest 50s, Germany). The distillate was titrated against 0.2 N H_2SO_4 until the endpoint (orange color). Protein content was calculated as nitrogen × 6.25. Crude fiber was determined by sequential boiling of 5.0 g sample with 200 mL of 1.25% H_2SO_4 (98%) for 30 min, followed by 200 mL of 1.25% NaOH for 30 min, using a fiber extraction unit (ANKOM 200, USA). The residue was ignited in a muffle furnace at 550 °C, and crude fiber was expressed as percentage weight loss relative to initial sample. Total carbohydrate was calculated by difference: 100 − (moisture + ash + protein + fat + crude fiber). The pH of the sample, indicating the concentration of free hydrogen ions, was measured using a calibrated pH meter (Model: Hanna HI2211). Titratable acidity of the samples was assessed according to AOAC with 0.1 N NaOH solution with an indicator of phenolphthalein.

Color measurement

Color parameters (L*, a*, and b*) of the samples were measured using a colorimeter (Model ZE6000, Nippon Denshoku Co., Japan). The instrument was calibrated with a standard white tile before measurement. The analysis was conducted in the CIE L*a*b* color space under the CIE standard illuminant D65 and using the CIE 10° standard observer**,** which are commonly applied settings for food color evaluation. In this color space, **L*** indicates lightness (ranging from black [0] to white [100]), a* indicates the red-green axis (positive values toward red and negative values toward green), and **b*** indicates the yellow-blue axis (positive values toward yellow and negative values toward blue). Chroma (C*)**,** representing the purity or saturation of color, was calculated using the formula: $C^* = \sqrt{(a^{*2} + b^{*2})}$ and Hue angle (h°)**,** indicating the dominant perceived color, was calculated as: $h° = \tan^{-1}(b^*/a^*)$ [11].

Determination of viscosity

The viscoelastic properties of kaya samples were analyzed using a controlled-stress rheometer (TA Instruments AR-G2, New Castle, DE, USA) equipped with a sandblasted flat plate geometry (40 mm diameter). The temperature was maintained at 25 ± 0.5 °C using a Peltier temperature control system. Samples were conditioned on the rheometer plate for 300 s prior to measurement. Steady shear viscosity was determined over a shear rate range of 0.1–50 s^{-1}. The data were recorded as shear stress versus shear rate and viscosity versus shear rate. For comparison, viscosity was also measured using a digital rotational viscometer (Brookfield DV3T, Middleboro, MA, USA) at 30 rpm and 50 rpm. Approximately 20 mL of sample was placed in the sample holder, equilibrated for 1–2 min, and viscosity readings were recorded in centipoise (cP) [12].

Determination of β-carotene

The β-carotene content of flour samples was determined following the method described by Halim et al. [13]. A solvent mixture of acetone and hexane (4:6, v/v) was prepared. Exactly 1.00 g of sample was homogenized with 15 mL of the solvent mixture using a homogenizer (Ultra-Turrax T25, IKA, Staufen, Germany). The homogenate was centrifuged at 3600 rpm (≈2000 × g) for 10 min at room temperature in a centrifuge (Hettich Rotina 380R, Tuttlingen, Germany). The resulting supernatant was collected, and an aliquot was transferred into a quartz cuvette. Absorbance was measured at 453 nm, 505 nm, and 663 nm using a UV–Vis spectrophotometer (Shimadzu UV-1800, Kyoto, Japan). The β-carotene content was calculated using the following equation [14]:

$$\beta\text{-Carotene (mg/100 g)} = 0.216A_{663} - 0.304A_{505} + 0.452A_{453}.$$

Microbiological Analysis

The standard spread plate technique was employed for Total Plate Count (TPC) and enumeration of viable yeast and mold microorganisms, following standard procedures [13]. Plate Count Agar (PCA; HiMedia, India) was used for TPC, and Potato Dextrose Agar (PDA; HiMedia, India) was used for yeast and mold enumeration. Both media were sterilized in an autoclave (Systec VX-95, Germany) at 121 °C and 103 kPa (15 psi) for 15 min. Serial dilutions were prepared by transferring 1.0 mL of homogenized sample into sterile test tubes containing 9.0 mL of distilled water. From each dilution, 0.1 mL was pipetted onto sterile Petri dishes (Tarsons, India) containing solidified PCA (for TPC) or PDA (for fungi). The inoculum was spread evenly with a sterile glass spreader (Hirschmann, Germany). For bacterial counts (TPC), inoculated PCA plates were incubated at 37 °C for 24–48 h in a microbiological incubator (Memmert IN110, Germany). For yeast and mold, PDA plates were incubated at 25–28 °C for 72 h in the same incubator. Only plates with 30–300 colonies were considered valid, and results were expressed as colony-forming units per gram (CFU/g) of sample.

Sensory Evaluation of the Kaya

The sensory evaluation of the kaya was performed by twenty semi-trained panelists from the Faculty of Life Science, Department of Daffodil International University, Bangladesh. The food samples were randomized and coded with three-digit random numbers and each sample was presented with a different number. The randomized order of the sample was presented once at a time to each panelist. Panelists were asked to evaluate the coded samples for sensory attributes, including color, aroma, texture, flavor, and overall acceptability, using a 9-point hedonic scale according to the method described by Halim et al. [13]. The scale ranged from 9 = extremely like, 8 = very much like, 7 = moderately like, 6 = slightly like, 5 = neither like nor dislike, 4 = dislike slightly, 3 = dislike moderately, 2 = dislike very much, and 1 = dislike extremely.

Statistical analysis

The results of each experiment, including the mean values and standard deviations, were obtained in triplicate. To identify the statistically significant differences between various formulations at a 95% confidence level, the experimental data were statistically analyzed using one-way analysis of variance (ANOVA). The significance of the discrepancies between the means was assessed using Duncan's multiple range test ($p \leq 0.05$). All statistical analyses were performed using IBM SPSS Statistics, version 22.**0** (IBM Corp., Armonk, NY, USA).

3-Result and discussion

Color values of jackfruit incorporated in kaya

Color is a critical quality attribute that strongly influences consumer perception of kaya. L*a*b* measurements (Table 2) revealed significant differences among formulations ($p \leq 0.05$). The control formulation (F1) exhibited the highest lightness (L*), reflecting a lighter yellow-green appearance due to higher pandan extract content. Pandan leaves contain natural pigments, including chlorophyll and carotenoids such as β-carotene, which contribute to yellow-green hues [15-16]. Incorporation of jackfruit puree (F2: 10%; F3: 20%) decreased L* values, particularly in F2, likely due to a darker caramel base that reduced lightness and yellowness. Redness (a*) increased with jackfruit addition, reflecting the natural orange coloration imparted by jackfruit carotenoids. F3, containing 20% jackfruit, showed a more intense orange hue, while F2 displayed a slightly darker tone due to caramelization effects. Yellowness (b*) was highest in F1 (26.95), consistent with the presence of pandan pigments and absence of jackfruit-derived pigments. Hue angle and chroma analyses confirmed uniform dispersion of jackfruit, producing a visually appealing product.

Mechanistically, these shifts are explained by pigment interactions and Maillard reactions during caramelization, which influence light reflection and absorption [17-18]. Similar trends have been reported in previous studies: Li et al. [19] observed that addition of carotenoid-rich fruit pulps to spreads increased redness (a*) and reduced lightness (L*) compared to control formulations. Troszyńska and Czubinski [20] also noted that fruit incorporation altered chroma and hue values, enhancing visual appeal and perceived freshness. The statistical differences observed ($p \leq 0.05$) in the present study validate that jackfruit concentration significantly affects color parameters. Overall, our results are consistent with prior research, confirming that fruit-derived carotenoids can serve as effective natural colorants while improving product appearance and consumer acceptability.

Table 2: Color values of jackfruit incorporated in kayaFormulation	Viscosity at 30 rpm	Viscosity at 50 rpm	pH	TSS (°Brix)	Titratable Acidity (%)
F1	4730.00±0.02^{c}	4352.00±0.01^{c}	3.55±0.01^{b}	55±0.01^{c}	0.33±0.01^{b}
F2	4884.33±0.02^{b}	4837.33±0.02^{b}	3.85±0.01^{b}	62±0.01^{b}	0.34±0.01^{b}
F3	11378.00±0.03^{a}	9243.67±0.01^{a}	4.33±0.01^{a}	68±0.00^{a}	0.38±0.01^{a}

Remark: F1- Pandan leaf incorporated Kaya, F2- 10% jackfruit-based kaya, and F3- 20% jackfruit-based kaya. L* =lightness color score, a*= redness color score, b*= yellowness color score. Mean ± standard deviation. $^{a\text{-}c}$ Different superscript alphabets in each column indicate significant differences among the formulations ($P \leq 0.05$).

Physicochemical composition of jackfruit incorporated kaya

Produced by entrepreneurs, jams, jellies, juices, and squashes often exhibit quality issues and fail to meet consumer expectations. Understanding the scientific principles underlying product formulation is essential for manufacturers to achieve key quality parameters, such as pH, total soluble solids (TSS), viscosity, and total sugar content. Viscosity, in particular, is a critical functional property that influences processing, texture, and consumer acceptability of kaya. In our study, the 10% (F2) and 20% (F3) jackfruit formulations showed significantly higher viscosities than the control (F1) ($p \leq 0.05$). This increase is mainly attributed to the soluble dietary fibers, pectin, and polysaccharides present in jackfruit pulp, which enhance water-binding capacity and gel-forming ability. During heating, breakdown of cell wall components releases additional soluble solids, further thickening the product [21]. These observations are consistent with prior reports showing that fruit-based products with higher fiber and pectin content exhibit increased viscosity [22–23]. Similarly, Ribeiro et al. [24] demonstrated that maltodextrin addition to avocado pulp increased viscosity, yield stress, and cohesiveness, highlighting the role of hydrocolloids in modulating rheological behavior. Moreover, Islam et al. [25] confirmed that pectin extracted from jackfruit by-products possesses good quality and can improve the thickening properties of food formulations. Previous studies also showed that jackfruit seed starch, rich in amylose, exhibits superior gel-forming properties compared to other starches, further supporting the contribution of jackfruit components to enhanced viscosity [26–28]. Understanding these effects is essential for optimizing processing parameters, including temperature, flow rate, and energy input, ensuring consistent product quality and functional performance in jackfruit-enriched kaya formulations [29].

Table 3: Viscosity and Physicochemical composition of jackfruit incorporated kaya

Formulation	L* value	a* value	b* value	Chroma (C*)	Hue angle (h°)
F1	44.51±0.01^{a}	9.95±0.01^{c}	26.95±0.02^{a}	28.72±0.01^{a}	82.00±0.01^{a}
F2	31.8±0.02^{c}	17.48±0.01^{b}	15.96±0.02^{c}	23.67±0.0^{bc}	39.35±0.01^{c}
F3	36.17±0.03^{b}	19.13±0.01^{a}	24.54±0.01^{b}	31.11±0.01^{b}	58.47±0.01^{b}

Remark: F1- Pandan leaf incorporated Kaya, F2- 10% jackfruit-based kaya, and F3- 20% jackfruit-based kaya. Mean ±standard deviation. $^{a-c}$ Different superscript alphabets in each column indicate significant differences among the formulations ($P \leq 0.05$).

The pH of the jam samples ranged from 3.55 to 4.33 (Table 3), slightly higher than the values reported by Eke-Ejiofor and Owuno [30] for pineapple (3.36) and jackfruit jam (3.35). Maintaining an optimal pH is critical, as it works synergistically with heat processing and reduced water activity to inhibit microbial growth and ensure long-term product stability [31]. A pH below 4.5 is particularly important for safety, as it prevents the growth of pathogenic microorganisms such as *Clostridium botulinum* (U.S. Department of Agriculture, 2025) [32]. Total soluble solids (TSS) ranged from 55 to 68 °Brix, consistent with Shokry et al. [33] and Salama et al. [34], reflecting high sugar content that reduces water activity, prolongs shelf life, and facilitates pectin–sugar–acid gelation for improved texture and mouthfeel [35].

Titratable acidity (TA) varied from 0.24% to 0.38%, with F3 showing the highest value, comparable to jackfruit jam (0.313 g/100 g) reported by Eke-Ejiofor and Owuno [30] but lower than olive jam values (0.66–0.70%) reported by Shokry [33]. Differences in TA may result from hydrolysis of pectic substances, oxidation of reducing sugars, or polysaccharide degradation during processing [36]. Acidity not only inhibits microbial growth but also enhances gel strength by optimizing pectin–sugar–acid interactions [37]. Statistical analysis ($p \leq 0.05$) confirmed significant differences among formulations, demonstrating that both fruit type and processing conditions influence physicochemical stability, aligning with prior studies emphasizing the importance of balancing pH, sugar concentration, and acidity for quality, stability, and consumer acceptability [30,32–34,36].

Nutritional composition of jackfruit incorporated in kaya

Controlling the moisture content of materials from the introduction of the raw materials to the packing of the finished product is essential for maximizing efficiency, optimizing yield, and producing a high-quality, consistent output. Higher moisture resulted in elasticity and hardness deficiency, which resulted in poor palatability [9]. High moisture content in processed food will also lead to spoilage.

From the study, moisture content for F1 has a significant difference (*p* ≤ 0.05, Table 4) from the other two formulations. Formulation F2 has the lowest (29.80%) moisture content compared to F1 (32.10%) and F3 (38.70%). These differences can be explained by fundamental water–solute interactions sugars bind water molecules through hydrogen bonding, while pectin network formation influences water retention and gel structure [38]. Our findings align with recent studies that reported moisture contents of 25 to 35% [39]. Within this context, F2 falls within the optimal range, F1 approaches the upper limit, while F3 exceeds it, indicating potential challenges in shelf life and palatability. This might be the result of research into variations in the components under study.

Ash content ranged from 0.20% in F3 to 0.50% in F1, reflecting differences in mineral density across formulations. Higher ash in F1 may result from greater inclusion of pulp fractions, while the lower value in F3 could reflect sugar dilution or mineral losses during processing. From a chemical perspective, ash represents the inorganic residue after combustion and reflects total mineral content, although the specific elements depend on raw material composition. The F1 value noted is greater than previous findings, which indicated 0.37% ash for sour-sop jam, but less than the 5.10% reported by Islam et al. [31] for pineapple jam. This could be linked to the proportion of the fruit pulp's composition. Tarwar et al. [40] similarly found 0.3% ash in guava jam, which aligns with our findings of 0.38%. Such variation illustrates how fruit species, inclusion of mineral-rich components, and processing practices directly influence mineral retention. Overall, the results highlight that formulation and processing strongly govern both water activity and mineral content, thereby determining the nutritional quality, texture, and stability of jam products.

The fat content in the jam samples ranged from 0.80% to 1.10%, with F1 showing the highest and F3 the lowest (Table 4). This is higher than previously reported for Kaya (0.49 g/100 g) [39], likely due to ingredient variations, particularly coconut milk, which is rich in medium-chain triglycerides. These fatty acids are readily absorbed, possess antimicrobial properties [41-42], and may help lower cholesterol, enhance shelf life, and make Kaya suitable for health-conscious individuals [43]. Jackfruit-incorporated kayas contained significant protein and modest fiber (Table 4). F2 had the highest protein (4.80%), exceeding previous reports (0.32%) [44], likely due to contributions from coconut milk and eggs. Protein supports immunity, muscle maintenance, and weight control [45], while fiber, as seen in F3 (2 g/100 g), contributes to glycemic control and cardiovascular health [46]. Total carbohydrate content varied significantly (p ≤ 0.05), with F3 containing 54.8 g/100 g compared to 61–62.7 g/100 g in F1 and F2. Lower carbohydrate content, influenced by fiber contributions and moisture interactions, can aid in energy regulation and obesity prevention, aligning with WHO recommendations for carbohydrate intake [47].

Table 4 Nutritional composition of jackfruit incorporated kaya

Formulation	Moisture (%)	Ash (%)	Protein (%)	Fat ^{Ns} (%)	Fiber (%)	Carbohydrate	β-carotene (mg/g)
F1	32.10±0.01^{b}	0.50±0.00^{a}	4.50±0.01^{a}	1.10±0.03^{a}	1.00±0.01^{a}	61.00±0.00^{a}	1.67±0.67^{a}
F2	29.80±0.01^{c}	0.30±0.00^{b}	4.80±0.03^{a}	1.00±0.02^{a}	1.50±0.01^{a}	62.70±0.00^{a}	1.25 ± 0.6^{b}
F3	38.70±0.01^{a}	0.20±0.13^{b}	3.50±0.01^{b}	0.80±0.03^{a}	2.00±0.01^{b}	54.80±0.00^{b}	2.57 ± 0.0^{b}

Remark: F1- Pandan leaf incorporated Kaya, F2- 10% jackfruit-based kaya, and F3- 20% jackfruit-based kaya. Mean ± standard deviation. $^{a-c}$ Different superscript alphabets in each column indicate significant differences among the formulations (*P* ≤ 0.05). Ns indicates not significant differences among the formulations (*P* ≥ 0.05).

β-Carotene, the primary provitamin A in carotenoid-rich foods, is essential for preventing vitamin A deficiency. In this study, β-carotene content differed significantly among formulations (F1 > F2, $p \leq 0.05$), with F1 showing higher levels, likely due to the inclusion of pandan leaves, which are naturally rich in carotenoids and more resistant to thermal degradation [48]. F2, containing more jackfruit, likely underwent greater heat-induced degradation during cooking, consistent with the known sensitivity of β-carotene to temperature, oxygen, and prolonged processing [13]. Lipids, such as coconut milk, may enhance carotenoid extractability and stability through micelle formation, affecting bioavailability. Mechanistically, β-carotene is metabolized to retinol equivalents (1 µg retinol = 1 RE) and further to retinaldehyde and retinoic acid, which are critical for vision, immunity, and cellular differentiation [13]. Previous studies have reported similar effects of ingredient source and processing on β-carotene retention in jams and fruit-based products [48]. Therefore, the observed differences reflect the combined effects of ingredient composition, thermal sensitivity, and food matrix interactions on β-carotene stability, emphasizing the importance of formulation in delivering functional provitamin A.

Table 5 Microbiological analysis of jackfruit incorporated kaya

Analysis	Formulation	Microbial load (CFU/g)
Total Plate count (CFU/g)	F1	3.5×10^4
	F2	3.1×10^4
	F3	2.0×10^4
Yeast and Mould count (CFU/g)	F1	2.0×10^4
	F2	2.3×10^4
	F3	2.5×10^4

Remark: F1- Pandan leaf incorporated Kaya, F2- 10% jackfruit-based kaya and F3- 20% jackfruit- based kaya

Microbiological Analysis

Table 5 shows the microbiological profile of jackfruit-incorporated kaya formulations, including Total Plate Count (TPC) and yeast/mold counts. The TPC values ranged from 2.0×10^4 CFU/g in F3 to 3.5×10^4 CFU/g in F1. These values fall within the generally accepted range for ready-to-eat fruit-based products (10^4–10^5 CFU/g) (International Commission on Microbiological Specifications for Foods [ICMSF], 2011), indicating that all formulations met microbial safety standards. Yeast and mold counts, however, were relatively higher, ranging between 2.0×10^4 and 2.5×10^4 CFU/g across samples, exceeding the recommended upper limits of 10^2–10^3 CFU/g (ICMSF, 2011). Among the formulations, F2 and F3 showed slightly higher yeast/mold loads compared to F1. The elevated yeast and mold count in F2 and F3 are likely explained by storage conditions, as samples were kept at room temperature for five days without preservatives. From a mechanistic perspective, higher sugar and moisture contents create favorable water activity (aw) levels for fungal growth. Jackfruit incorporation may have introduced additional fermentable sugars and organic substrates that supported yeast and mold proliferation, while the natural acidity of kaya provided only partial inhibition. This aligns with the principle that microbial growth depends on the interplay of pH, water activity, nutrient availability, and storage environment [49]. Compared with earlier studies on tropical fruit jams and spreads, which reported yeast and mold counts below detectable limits under refrigerated or preservative-stabilized storage [50], the present findings suggest that the absence of preservation strategies markedly influences microbial stability. Nonetheless, bioactive compounds in pandan leaves and β-carotene from jackfruit, both of which possess antioxidant and antimicrobial properties, may have contributed to moderating microbial proliferation [51]. Overall, while the TPC levels confirm acceptable safety, the elevated yeast/mold counts highlight the importance of incorporating mild preservation techniques or optimized storage conditions to enhance product shelf life.

Sensory evaluation of jackfruit incorporated kaya

There were no significant differences ($p \geq 0.05$) in the sensory parameters assessed, except for overall acceptance, which showed a significant difference ($p \leq 0.05$) as indicated in Table 6. In all parameters, formulations F1 and F3 had the highest acceptance rate. However, formulation F2 scored lowest in all parameters, compared to the other samples. In terms of color, the highest acceptance was recorded (7) in formulation F1. It may be due to the green color of pandan leaves, which makes it unique among all samples. The analysis showed that samples F1 and F2 were significantly similar in terms of texture. The score of overall acceptance followed the same trend. This suggests that kaya formulated with jackfruit did affect the flavor and overall acceptance of the products. Furthermore, the higher sensory score of flavor and taste for sample F1 and sample F3 meets one of our objectives of this study to improve the taste and flavor of kaya. Moreover, the sensory score of overall acceptance of the samples made it obvious that sample F3 was the most preferred, and sample F2 was liked moderately. This is in agreement with the research conducted by Mohd et al. [1] and Gambang [52], which stated that people wanted to have a new taste and flavor for kaya.

Table 6 Sensory evaluation of jackfruit incorporated kaya

Formulation	Color ^{Ns}	Flavor ^{Ns}	Texture ^{Ns}	Taste ^{Ns}	Overall acceptance
F1	7.00±1.06^{a}	6.58±1.24^{a}	6.88±1.07^{a}	6.83±1.27^{a}	7.25±1.40^{a}
F2	6.33±1.23^{a}	6.38±1.09^{a}	6.83±1.00^{a}	6.63±1.09^{a}	6.96±1.12^{b}
F3	6.63±1.13^{a}	6.38±1.37^{a}	7.13±1.03^{a}	6.88±1.48^{a}	7.25±1.07^{a}

Remark: F1- Pandan leaf incorporated Kaya, F2- 10% jackfruit-based kaya, and F3- 20% jackfruit-based kaya. Mean ± standard deviation. $^{a-b}$ Different superscript alphabets in each column indicate significant differences among the formulations ($P \leq 0.05$). Ns indicates not significant differences among the formulations ($P \geq 0.05$).

4-Conclusion

In the current health-conscious era, consumers increasingly demand foods that are safe, nutritious, low in fat, calorie-conscious, and palatable, while remaining affordable. This study demonstrates that jackfruit, a frequently underutilized fruit, can be effectively processed into high-quality jam (kaya) that meets these criteria. The produced jackfruit jam exhibited substantial nutrient content, particularly in micronutrients, and was microbiologically safe. Incorporating jackfruit into jam not only preserves the fruit, extending its shelf life, but also reduces postharvest losses, enhances farmers' income opportunities, and provides an alternative to conventional fruits in jam production. Overall, jackfruit-based jam represents a sustainable, nutritious, and commercially viable product that aligns with contemporary consumer preferences and food industry demands.

5-Ethical Statement

Except for sensory evaluation, we have not conducted any human or animal investigations during this study. Regarding the sensory case.

Author Contribution

Md. Shakhawat Hossain and Md. Abdul Halim: Formal analysis, Investigation, Methodology, Software, writing – original draft, Writing – review & editing. Conceptualization, Resources, Supervision.

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