



RESEARCH ARTICLE

Development and storage stability of custard apple (*Annona squamosa* L.) and banana instant beverage mix: Physicochemical, sensory and microbial quality evaluation

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Abstract

Custard apple (*Annona squamosa* L.) is a highly nutritious yet underutilised fruit owing to its seasonal availability and short postharvest life. The present study aimed to develop a shelf-stable instant ready-to-serve (RTS) beverage mix using spray-dried custard apple powder and banana powder and to evaluate its physicochemical, sensory, microbial and economic characteristics during ambient storage. Six formulations containing varying proportions of custard apple powder (5.0–17.5 %) and banana powder (15.0–2.5 %) were prepared, packed in aluminium (Al) pouches and stored under ambient conditions for 90 days. The formulations were analysed at monthly intervals for moisture content, water activity, proximate composition, sugar profile, sensory attributes, microbial quality and economic feasibility. Storage resulted in a gradual increase in moisture content, water activity, reducing sugars and total sugars, whereas carbohydrate, protein, fat, ash and non-reducing sugar contents decreased slightly over time. Significant differences ($p \leq 0.01$) were observed among formulations for both physicochemical and sensory characteristics. The formulation containing 10 % custard apple powder and 10 % banana powder (T_3) exhibited the most desirable quality attributes, with superior colour and appearance, mouthfeel, taste and overall acceptability throughout storage. Furthermore, no bacterial or fungal growth was detected in any treatment during the 90 days storage period, indicating excellent microbiological stability. Although the formulation containing 5 % custard apple powder and 15 % banana powder generated the highest economic returns, the 10 : 10 blend demonstrated the best balance between nutritional quality, sensory acceptability and storage stability. Overall, the findings demonstrate that spray-dried custard apple powder can be successfully utilised in the development of a shelf-stable instant RTS beverage mix, offering a promising value-addition strategy for the commercial utilisation of custard apple fruits.

Keywords: banana powder; custard apple powder; functional beverage; instant beverage mix; sensory evaluation; spray drying; storage stability

Introduction

The global food industry has witnessed a substantial shift towards the development of convenient, nutritious and shelf-stable food products in response to changing consumer lifestyles and increasing health awareness. Among these products, fruit-based beverage powders have gained considerable attention owing to their ease of preparation, extended shelf life, reduced transportation costs and ability to retain essential nutrients and bioactive compounds (1). Instant beverage mixes prepared from fruit powders offer an attractive alternative to fresh fruits by ensuring year-round availability, minimising postharvest losses and providing consumers with convenient access to fruit-derived

nutrients. Consequently, the development of functional fruit-based powdered beverages has emerged as an important area of research for the food processing industry (2).

Spray drying is one of the most widely employed technologies for the production of fruit powders because of its operational efficiency, scalability and ability to produce stable powders with desirable physicochemical properties (3). The technology converts liquid fruit pulps and juices into free-flowing powders through rapid moisture removal, thereby improving product stability and facilitating incorporation into various food formulations. Spray-dried fruit powders have been successfully utilised in dairy products, bakery products, confectionery items,

nutritional supplements and beverage formulations (4). Furthermore, the production of fruit powders contributes significantly to reducing seasonal fluctuations in fruit availability and enhances the commercial utilisation of highly perishable horticultural commodities (5).

Custard apple (*Annona squamosa* L.), belonging to the family Annonaceae, is an important tropical fruit cultivated in several countries including India, Brazil, Thailand, Philippines and parts of Africa. The fruit is known for its unique flavour, creamy texture and pleasant sweetness (6). Nutritionally, custard apple is a rich source of carbohydrates (24 g), protein (1.7 g), fat (0.5 g), dietary fibre (3 g), vitamins (40 mg/100 g) and various bioactive compounds including phenolics, flavonoids, alkaloids and acetogenins. These compounds have been associated with antioxidant, anti-inflammatory, antimicrobial and health-promoting properties. The fruit pulp contains appreciable amounts of natural sugars and micronutrients, making it suitable for the development of value-added functional food products. Recent scientific investigations have further highlighted the potential of custard apple as a promising source of nutraceutical ingredients and bioactive compounds for food and pharmaceutical applications (7).

Despite its nutritional and economic significance, the commercial utilisation of custard apple remains limited due to its highly perishable nature. The fruit exhibits rapid ripening after harvest and generally possesses a very short shelf life under ambient conditions. The soft texture and susceptibility to physiological deterioration result in substantial quantitative and qualitative postharvest losses during handling, transportation and marketing. Moreover, the seasonal availability of custard apple restricts its utilisation and market accessibility throughout the year. These limitations have necessitated the development of suitable processing technologies capable of extending shelf life and enhancing product diversification. Conversion of custard apple pulp into stable powder form through dehydration technologies represents an effective strategy for reducing postharvest losses while enabling the development of innovative food products with improved storage stability and market potential (6).

In recent years, increasing attention has been directed towards the utilisation of fruit powders as functional ingredients in beverage formulations. Fruit-based beverage powders offer several advantages, including ease of storage, rapid reconstitution, desirable sensory characteristics and enhanced nutritional value. However, the successful development of an instant beverage mix depends not only on the quality of the primary fruit ingredient but also on the incorporation of complementary ingredients that improve flavour, texture, mouthfeel and consumer acceptability. In this regard, banana powder represents a promising ingredient owing to its natural sweetness, carbohydrate richness, pleasant flavour profile and thickening properties. Banana powder has been widely explored in food formulations because of its ability to improve sensory quality, contribute natural sugars and enhance the rheological characteristics of reconstituted products (8). Additionally, banana contains dietary fibre, resistant starch, potassium and various micronutrients that may further improve the nutritional profile of beverage formulations (9).

The combination of custard apple powder and banana powder offers a unique opportunity for the development of a nutritionally enriched instant beverage system. Custard apple contributes characteristic flavour, natural sugars and bioactive

compounds, whereas banana powder provides desirable mouthfeel, sweetness and product stability (10). The synergistic interaction between these ingredients may improve overall sensory quality and consumer acceptance while maintaining nutritional integrity. Furthermore, blending fruit powders can facilitate optimisation of product characteristics that are often difficult to achieve using a single fruit ingredient. Such combinations are particularly relevant in the development of instant beverage mixes intended for commercial production and long-term storage (2).

Although substantial progress has been made in the development of fruit powder-based foods and beverages, information regarding the utilisation of spray-dried custard apple powder in shelf-stable instant beverage formulations remains limited. Most previous investigations have primarily focused on spray-drying optimisation, powder characterisation, or development of fresh fruit beverages. Furthermore, studies evaluating the combined effect of custard apple powder and banana powder on physicochemical properties, sensory quality, microbial safety and storage stability under ambient conditions are scarce. The absence of comprehensive information regarding the optimisation of custard apple-banana powder blends restricts the commercial exploitation of these fruit resources and limits opportunities for product diversification within the beverage sector (11–13). Therefore, the present study aimed to develop and optimise a spray-dried custard apple-banana instant beverage mix and evaluate its physicochemical properties, sensory quality, microbial safety and storage stability under ambient conditions.

Materials and Methods

Materials

Fully mature custard apple (*A. squamosa*) fruits were procured from local orchards in Belagavi, Karnataka, India, during September 2021 and used for the preparation of spray-dried custard apple powder. Raw banana fruits (cv. Kothia) were obtained from the All India Coordinated Research Project (AICRP) on Fruits, Kittur Rani Channamma College of Horticulture, Arabhavi, Karnataka, India. Food-grade maltodextrin (DE 20), sugar, citric acid and other analytical-grade chemicals required for quality evaluation were procured from local suppliers.

Preparation of spray-dried custard apple powder

Custard apple pulp was extracted manually from ripe fruits and diluted with water in a 1 : 5 ratio. Maltodextrin was incorporated at 20 % (w/w on total feed basis) as a carrier agent and the mixture was homogenised for 8–10 min to obtain a uniform feed solution. The feed was filtered through a double-layer sieve and subsequently spray-dried using a laboratory-scale spray dryer (LSD-48, Techno Search and Systems Pvt. Ltd., Thane, India) with inlet temperature (175 °C), outlet temperature (90 °C) and feed flow rate (2 mL min⁻¹). The resulting powder was collected, packed in 50 µm aluminium (Al) laminate pouches and stored at 25 °C and 60 % relative humidity under ambient conditions until further use (14).

Preparation of banana powder

Fresh green banana fruits were washed, blanched at 80 °C for 2–3 min and cooled immediately with water, peeled and sliced uniformly. The slices were immersed in 0.2 % potassium metabisulphite (K₂S₂O₅) solution for 15 min to minimise enzymatic browning. Treated slices were dehydrated in a tray dryer at 65 °C for

7–8 hr until a constant weight was achieved. The dried slices were milled into a fine powder, packed in 50 µm Al laminate pouches and stored at ambient temperature.

Formulation of instant beverage mix

Based on preliminary trials the experiment was conducted in a completely randomised design (CRD) comprising 6 formulations and 4 replications. Instant beverage mixes were prepared by blending spray-dried custard apple powder and banana powder in different proportions as follows:

- T₁: 5.0 % custard apple powder + 15.0 % banana powder
- T₂: 7.5 % custard apple powder + 12.5 % banana powder
- T₃: 10.0 % custard apple powder + 10.0 % banana powder
- T₄: 12.5 % custard apple powder + 7.5 % banana powder
- T₅: 15.0 % custard apple powder + 5.0 % banana powder
- T₆: 17.5 % custard apple powder + 2.5 % banana powder

The prepared mixes were packed in 50 µm Al laminate pouches and stored under ambient conditions for 90 days.

Preparation of reconstituted beverage

The beverage was prepared by dispersing the instant beverage mix in 200 mL of potable water. The total soluble solids were adjusted to 15° Brix using sucrose, while acidity was standardised to 0.3 % using citric acid. The reconstituted beverage was used for sensory evaluation (Fig. 1).

Storage study

The packaged instant beverage mixes were stored under ambient laboratory conditions for three months. Samples were analysed initially and subsequently at 30-day intervals (30, 60 and 90 days) to determine changes in physicochemical, sensory and microbial characteristics.

Physicochemical analysis

Water activity (a_w) and moisture content (%)

Moisture content was determined using moisture analyser. 1 g of each sample was placed in moisture analyser (Model: P1019319, A and D Company Limited, Japan) and water activity was measured using water activity meter (Model: Novasia AG, Switzerland) by placing instant-beverage-mix sample into sample chamber. The observation was directly read in the instrument after it was stabilised.

Carbohydrates (%)

Total carbohydrate content was estimated using the anthrone method following hydrolysis of the sample with hydrochloric acid (HCl) and subsequent colorimetric measurement at 660 nm (15).

Protein content (%)

Protein content was determined by the Lowry method (16). A 500 mg sample was extracted with 5–10 mL buffer, centrifuged and the supernatant was used for analysis. Aliquots of the extract were made up to 1 mL, followed by the addition of 5 mL of reagent C. The mixture was incubated in the dark at room temperature for 30 min and absorbance was measured at 660 nm. Protein concentration was determined using a bovine serum albumin (BSA) standard curve and expressed as percentage (%).

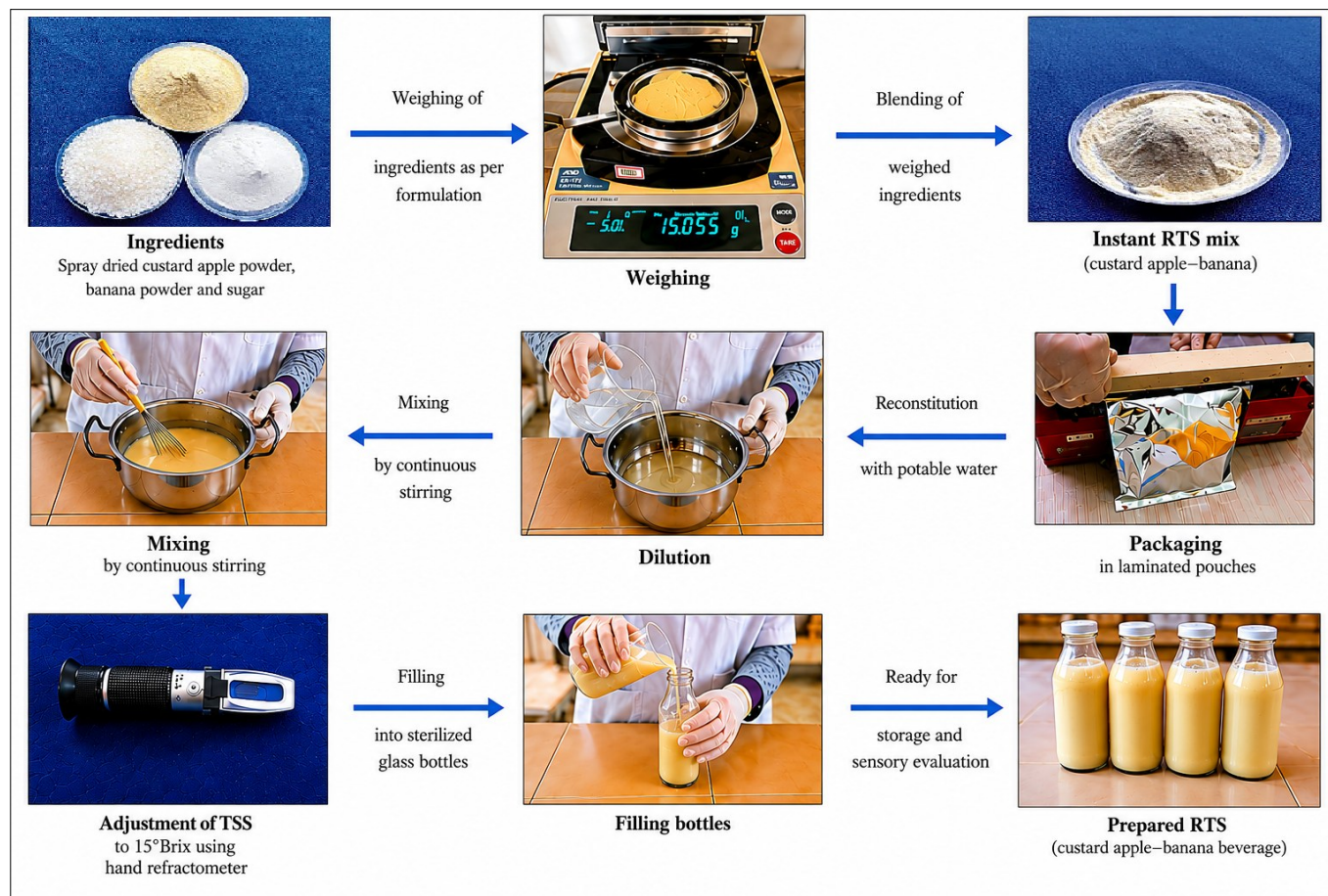


Fig. 1. Workflow illustrating the sequential steps involved in the preparation of custard apple-banana ready-to-serve (RTS) beverage from instant beverage mix.

Fat content (%)

Fat content was estimated using a Soxhlet apparatus extraction system with petroleum ether as the solvent. The extracted fat was quantified gravimetrically following solvent evaporation (17).

$$\text{Fat content (\%)} = \frac{\text{Final weight (g)} - \text{Initial weight (g)}}{\text{Weight of the sample (g)}} \times 100$$

Ash content (%)

Ash content was determined by incinerating 5 g of sample in a muffle furnace at 550 ± 25 °C until constant weight, following standard procedures (18).

$$\text{Total ash content} = \frac{C - A}{B - A} \times 100$$

where,

A: Weight of empty crucible

B: Weight of sample + crucible

C: Weight of sample after ashing

Reducing sugars (%)

Reducing sugars were estimated using the Lane and Eynon titrimetric method (19) following clarification of the sample extract with basic lead acetate and subsequent deleading with potassium oxalate. The clarified filtrate was titrated against Fehling's solution using methylene blue as an indicator and the reducing sugar content was expressed as percentage glucose equivalent.

Reducing sugars (%) =

$$\frac{\text{Glucose equivalent (0.052)} \times \text{Total volume made up}}{\text{Titre value} \times \text{Weight of sample}} \times 100$$

Total sugars (%)

Total sugars were determined by the Lane and Eynon method (19) after acid inversion of the clarified filtrate using diluted hydrochloric acid (HCl). The inverted solution was neutralised with sodium hydroxide and titrated against Fehling's solution. Total sugars were expressed as percentage invert sugar.

Total sugars (%) =

$$\frac{\text{Glucose equivalent (0.052)} \times \text{Total volume made up}}{\text{Titre value} \times \text{Weight of sample} \times \text{aliquote taken for sample}} \times 100$$

Non-reducing sugars (%)

Non-reducing sugars were calculated from the difference between total sugars and reducing sugars using the following equation:

Non-reducing sugars (%) =

$$[\text{Total sugars (\%)} - \text{Reducing sugars (\%)}] \times 0.95$$

Sensory evaluation

Sensory quality of the reconstituted beverage was assessed by a panel of 10 semi-trained members consisting of faculty and postgraduate students. Samples were evaluated using a nine-point hedonic scale for colour and appearance, aroma, mouthfeel, taste and overall acceptability. Randomised coding was employed to eliminate bias during evaluation.

Microbiological analysis

Total plate count (TPC), coliform count and yeast and mould count were determined at monthly intervals during storage according to a previously studied method (19). 1 g of sample was serially diluted in

sterile diluent to obtain a 10^{-1} dilution and 1 mL aliquots of this dilution were plated on plate count agar (PCA), MacConkey agar and potato dextrose agar (PDA) for the enumeration of total viable bacteria, coliforms and yeasts and moulds, respectively. Plates were incubated at 35 °C for 48 hr for TPC, at 37 °C for 24 hr for coliforms and at 32 °C for 72 hr for yeast and mould, after which colonies were counted. Based on the dilution and plating volume used, the detection limit of the method was 10 CFU g⁻¹. Microbial counts were expressed as colony-forming units per gram (CFU g⁻¹) of sample.

Economic analysis

Economic feasibility of each formulation was evaluated by calculating the total production cost, gross return, net return and return per rupee of expenditure using the prevailing market prices of raw materials and finished products. Total production cost was calculated by summing the costs of custard apple powder, banana powder, sugar, citric acid, labour, packaging materials and depreciation of equipment. Gross return was calculated based on the prevailing selling price of the prepared ready-to-serve (RTS) beverage and the quantity of instant beverage mix required for its preparation. Net return was calculated as the difference between gross return and total production cost, while return per rupee of expenditure was calculated as the ratio of gross return to total production cost. The calculations were expressed as follows:

Total production cost (A) = Ingredient cost + Labour cost + Packaging cost + Depreciation cost

Net return = Gross return (B) - Total production cost (A)

Return per rupee of expenditure

$$= \text{Gross return (B)} / \text{Total production cost (A)}$$

Statistical analysis

The experiment was laid out in a CRD with 4 replications. Experimental data on physicochemical, sensory, microbial and economic parameters were analysed using analysis of variance (ANOVA) in GRAPES Agri1 Statistical Software Version 1.1.0. Significant differences among treatment means were determined using Duncan's new multiple range test (DNMRT) at $p \leq 0.01$. The results are expressed as mean $\pm$ standard deviation of four replications. To facilitate multivariate interpretation and comparison among treatments, a heat map based on standardised data was constructed to visualise patterns and associations among the studied quality attributes.

Results and Discussion

Moisture content and water activity

Moisture content and water activity are important indicators of the storage stability and microbial safety of powdered food products. Both parameters were significantly affected by formulation and storage duration (Table 1). Moisture content ranged from 10.34–12.45 %, while water activity varied between 0.42 and 0.55 during the storage period. Formulations containing higher proportions of custard apple powder exhibited significantly higher moisture content and water activity than those containing greater levels of banana powder. The highest moisture content was recorded in T₆, increasing from 12.32 % initially to 12.45 % after 90 days of storage, whereas the lowest values were observed in T₁, increasing from 10.34–10.46 %. A similar trend was observed for water activity, with the highest values recorded in T₆ (0.50–0.55) and the lowest in T₁ (0.42–0.48).

Table 1. Effect of formulation and storage on moisture content (%) and water activity (aw) of custard apple-banana instant beverage mix

Treatment	Moisture content (%)				Water activity (aw)			
	Initial	1 MAS	2 MAS	3 MAS	Initial	1 MAS	2 MAS	3 MAS
T ₁	10.34 ± 0.08 ^f	10.37 ± 0.08 ^f	10.41 ± 0.07 ^f	10.46 ± 0.06 ^f	0.42 ± 0.03 ^d	0.42 ± 0.05 ^d	0.45 ± 0.01 ^d	0.48 ± 0.02 ^d
T ₂	10.66 ± 0.07 ^e	10.68 ± 0.07 ^e	10.71 ± 0.04 ^e	10.75 ± 0.07 ^e	0.44 ± 0.03 ^c	0.45 ± 0.01 ^c	0.46 ± 0.01 ^c	0.49 ± 0.03 ^c
T ₃	11.10 ± 0.09 ^d	11.12 ± 0.10 ^d	11.15 ± 0.07 ^d	11.18 ± 0.01 ^d	0.46 ± 0.02 ^{bc}	0.46 ± 0.06 ^{bc}	0.48 ± 0.01 ^c	0.53 ± 0.04 ^b
T ₄	11.34 ± 0.10 ^c	11.37 ± 0.01 ^c	11.41 ± 0.08 ^c	11.43 ± 0.01 ^c	0.47 ± 0.03 ^b	0.49 ± 0.01 ^b	0.50 ± 0.01 ^b	0.53 ± 0.04 ^b
T ₅	11.71 ± 0.08 ^b	11.73 ± 0.01 ^b	11.75 ± 0.01 ^b	11.79 ± 0.01 ^b	0.48 ± 0.01 ^{ab}	0.49 ± 0.01 ^b	0.51 ± 0.01 ^{ab}	0.54 ± 0.01 ^{ab}
T ₆	12.32 ± 0.01 ^a	12.35 ± 0.01 ^a	12.39 ± 0.01 ^a	12.45 ± 0.01 ^a	0.50 ± 0.01 ^a	0.51 ± 0.01 ^a	0.52 ± 0.01 ^a	0.55 ± 0.01 ^a

Values are expressed as mean ± standard deviation (n = 4). Means followed by different superscript letters within a column differ significantly at $P \leq 0.01$. MAS: months after storage.

The higher moisture content and water activity of custard apple-rich formulations may be attributed to the hygroscopic nature of spray-dried fruit powders. Custard apple powder contains appreciable amounts of low-molecular-weight sugars and amorphous constituents that readily absorb moisture from the environment (20). In contrast, banana powder contains higher levels of starch and structural carbohydrates, which exhibit comparatively lower hygroscopicity. Similar behaviour has been reported in spray-dried fruit powders and beverage formulations, where moisture sorption is strongly influenced by sugar composition, amorphous structure and storage conditions (21).

Storage duration significantly influenced both parameters, resulting in a gradual increase throughout the 90 days storage period. Mean moisture content increased from 11.25–11.34 %, while mean water activity increased from 0.46–0.52. The increase may be attributed to gradual moisture adsorption from the surrounding environment and the tendency of fruit powders to attain equilibrium moisture content during storage. Comparable increases in moisture content and water activity during storage have been reported for spray-dried fruit powders and powdered beverage systems (12). From a physical stability perspective, moisture uptake may act as a plasticiser in the amorphous powder matrix, lowering the glass transition temperature (T_g) and increasing molecular mobility, which can promote undesirable changes such as stickiness, caking and loss of powder stability during storage (4).

Despite these changes, the magnitude increase remained relatively small, indicating satisfactory storage stability of the beverage mixes. Importantly, water activity remained below levels favourable for microbial growth, which likely contributed to the absence of detectable bacterial and fungal contamination throughout storage. Similar observations have been reported in dehydrated fruit powders, where low water activity effectively restricts microbial proliferation and contributes to product stability during storage (12, 13). The findings demonstrate that although increasing custard apple powder concentration enhanced moisture uptake, all formulations maintained acceptable physicochemical stability and were suitable for ambient storage for at least 90 days.

Effect of formulation and storage on proximate composition

The proximate composition of the instant beverage mix was significantly influenced by the custard apple-to-banana powder ratio and storage duration (Table 2). Formulations containing higher proportions of banana powder exhibited greater carbohydrate levels, whereas increasing custard apple powder concentration enhanced protein content. The highest carbohydrate content was recorded in T₁ (32.15 %), followed by T₂ (32.06 %), while T₆ contained the lowest level (31.84 %) at the beginning of storage. This difference

can be attributed to the high starch content of green banana powder, which contributed substantially to the carbohydrate fraction of the beverage mix. Similar observations have been reported in banana powder-enriched food formulations, where starch-rich banana powder significantly increased carbohydrate content (8, 9). During storage, carbohydrate content declined marginally across all formulations, with T₁ decreasing from 32.15–31.95 % and T₆ from 31.84–31.66 % after 90 days. The reduction was likely associated with the gradual hydrolysis of complex carbohydrates into simpler sugars, as evidenced by the concurrent increase in reducing and total sugars during storage. Comparable declines in carbohydrate content have been reported in stored fruit powder blends and dehydrated food systems (2, 13).

Protein content exhibited an opposite trend, increasing with greater incorporation of custard apple powder. The highest protein content was observed in T₆ (2.90 %), closely followed by T₅ (2.89 %), whereas T₁ recorded the lowest value (2.84 %) at the start of storage. Although a slight decline was observed during storage, the reduction was limited, with protein values ranging between 2.78 and 2.82 % after 90 days. Such reductions may be associated with non-enzymatic interactions between amino compounds and reducing sugars occurring during storage of low-moisture food systems. Similar decreases in protein content during storage have been reported in fruit powder mixtures and powdered food products, where storage-induced physicochemical reactions contribute to minor compositional changes (2, 12).

Fat content remained comparatively low in all formulations (0.29–0.42 %) and decreased gradually during storage. T₁ exhibited the highest fat content (0.42 %), whereas T₆ showed the lowest value (0.32 %) initially. After 90 days, fat content decreased to 0.37 and 0.29 %, respectively. The decline may be attributed to oxidative degradation of lipid components during storage, although the limited magnitude of change suggests that Al laminate packaging effectively restricted oxidative deterioration. Similar reductions in fat content during storage have been documented in dehydrated fruit products and powdered beverage formulations (12, 13).

Despite these compositional changes, the reductions in carbohydrate, protein and fat contents were relatively small and did not adversely affect the nutritional quality of the beverage mixes. Among the formulations, T₃ (10 % custard apple powder + 10 % banana powder) provided a balanced nutritional profile while simultaneously achieving the highest sensory acceptance, indicating its suitability as the optimum formulation. Similar findings have been reported for fruit powder-based beverage systems, where balanced ingredient combinations contributed to improved nutritional quality and consumer acceptability (2, 9).

Table 2. Effect of formulation and storage on proximate composition of custard apple-banana instant beverage mix

Treatment	Carbohydrate (%)				Protein (%)				Fat (%)				Ash (%)			
	Initial	1 MAS	2 MAS	3 MAS	Initial	1 MAS	2 MAS	3 MAS	Initial	1 MAS	2 MAS	3 MAS	Initial	1 MAS	2 MAS	3 MAS
T ₁	32.15 ± 0.04 ^a	32.11 ± 0.01 ^a	32.07 ± 0.04 ^a	31.95 ± 0.03 ^a	2.84 ± 0.07 ^c	2.83 ± 0.04 ^c	2.81 ± 0.03 ^c	2.78 ± 0.02 ^c	0.42 ± 0.04 ^a	0.42 ± 0.03 ^a	0.40 ± 0.03 ^a	0.37 ± 0.05 ^a	1.37 ± 0.01 ^a	1.36 ± 0.04 ^a	1.34 ± 0.01 ^a	1.31 ± 0.05 ^a
T ₂	32.06 ± 0.01 ^b	32.04 ± 0.01 ^b	31.98 ± 0.05 ^b	31.90 ± 0.01 ^b	2.85 ± 0.03 ^c	2.84 ± 0.03 ^c	2.82 ± 0.02 ^c	2.79 ± 0.02 ^c	0.41 ± 0.02 ^a	0.39 ± 0.04 ^{ab}	0.38 ± 0.04 ^a	0.36 ± 0.03 ^a	1.34 ± 0.01 ^b	1.34 ± 0.01 ^b	1.32 ± 0.01 ^b	1.29 ± 0.01 ^b
T ₃	32.00 ± 0.01 ^c	31.98 ± 0.01 ^c	31.91 ± 0.02 ^c	31.84 ± 0.01 ^c	2.85 ± 0.04 ^c	2.84 ± 0.02 ^c	2.82 ± 0.01 ^c	2.78 ± 0.01 ^c	0.40 ± 0.04 ^{ab}	0.36 ± 0.03 ^b	0.35 ± 0.04 ^{ab}	0.34 ± 0.05 ^{ab}	1.33 ± 0.01 ^c	1.33 ± 0.01 ^c	1.32 ± 0.01 ^b	1.28 ± 0.01 ^{bc}
T ₄	31.94 ± 0.01 ^d	31.90 ± 0.01 ^d	31.85 ± 0.03 ^d	31.74 ± 0.01 ^d	2.87 ± 0.02 ^b	2.86 ± 0.02 ^b	2.82 ± 0.01 ^c	2.79 ± 0.01 ^c	0.36 ± 0.04 ^b	0.34 ± 0.03 ^b	0.32 ± 0.05 ^b	0.32 ± 0.05 ^b	1.31 ± 0.01 ^d	1.30 ± 0.01 ^d	1.28 ± 0.06 ^c	1.25 ± 0.05 ^c
T ₅	31.88 ± 0.01 ^e	31.84 ± 0.01 ^e	31.78 ± 0.01 ^e	31.70 ± 0.01 ^e	2.89 ± 0.04 ^{ab}	2.87 ± 0.05 ^{ab}	2.86 ± 0.02 ^{ab}	2.81 ± 0.01 ^b	0.35 ± 0.03 ^b	0.34 ± 0.03 ^b	0.32 ± 0.06 ^b	0.31 ± 0.04 ^b	1.29 ± 0.01 ^e	1.29 ± 0.01 ^e	1.27 ± 0.01 ^d	1.23 ± 0.01 ^d
T ₆	31.84 ± 0.01 ^f	31.82 ± 0.01 ^f	31.76 ± 0.01 ^f	31.66 ± 0.01 ^f	2.90 ± 0.04 ^a	2.89 ± 0.07 ^a	2.86 ± 0.01 ^a	2.82 ± 0.01 ^a	0.32 ± 0.03 ^b	0.32 ± 0.03 ^b	0.30 ± 0.04 ^b	0.29 ± 0.02 ^b	1.28 ± 0.01 ^f	1.27 ± 0.01 ^f	1.25 ± 0.03 ^e	1.22 ± 0.01 ^e

Values are expressed as mean ± standard deviation (n = 4). Means followed by different superscript letters within a column differ significantly at $P \leq 0.01$. MAS: months after storage.

Ash content was significantly affected by formulation and storage duration (Table 2). The initial ash content of the instant beverage mixes ranged from 1.28–1.37 %, with T₁ exhibiting the highest value (1.37 %) and T₆ the lowest (1.28 %). The higher ash content observed in formulations containing greater proportions of banana powder may be attributed to the relatively higher mineral contribution of banana compared with custard apple powder. Similar observations have been reported in banana powder-enriched food formulations, where banana powder contributed significantly to the total mineral content of the final product (8, 9).

Despite the observed reduction, the ash content remained comparatively stable throughout the storage period, indicating minimal loss of mineral constituents. Similar stability of mineral content during storage has been reported in fruit powder-based products and functional beverage formulations (2). These findings suggest that the developed beverage mixes retained their mineral quality during ambient storage and that the custard apple-banana powder blends provided a nutritionally stable product with respect to total mineral content.

Changes in sugar profile during storage

The sugar profile of the instant beverage mix was significantly influenced by formulation composition and storage duration (Table 3). Irrespective of treatment, reducing sugars and total sugars increased progressively during storage, whereas non-reducing sugars exhibited a corresponding decline, indicating the occurrence of hydrolytic transformations within the product matrix.

Reducing sugar content increased from 3.87–3.99 % initially to 4.95–5.16 % after 90 days of storage. Formulations containing higher proportions of custard apple powder recorded comparatively greater reducing sugar levels, with T₆ exhibiting the highest values throughout storage (3.99 % initially and 5.16 % after 90 days), whereas T₁ recorded the lowest values (3.87 and 4.95 %, respectively). The higher reducing sugar content in custard apple-rich formulations may be attributed to the naturally higher concentration of readily available sugars present in custard apple pulp. The progressive increase during storage is likely associated with the hydrolysis of sucrose and other complex carbohydrates into simpler reducing sugars, a phenomenon commonly observed in fruit-based dehydrated products and beverage formulations during storage (22, 23). Similar increases in reducing sugar content have also been reported in fruit powder blends and spray-dried products, where storage-induced carbohydrate degradation contributes to the formation of simpler sugar fractions (2, 12).

In contrast, non-reducing sugars decreased consistently during storage, declining from a mean value of 10.45 % at the beginning of storage to 9.80 % after 90 days. T₁ recorded the highest non-reducing sugar content (10.53 % initially and 9.88 % after storage), whereas T₆ exhibited the lowest values (10.37 and 9.73 %, respectively). The decline in non-reducing sugars can be attributed to sucrose inversion and subsequent conversion into reducing sugars under storage conditions. The inverse relationship observed between reducing and non-reducing sugars further supports the occurrence of these hydrolytic reactions during storage. Comparable reductions in non-reducing sugars have been documented in stored fruit beverages and powdered food systems, where sucrose degradation is accelerated by storage time and moisture absorption (13, 23).

Table 3. Effect of formulation and storage on sugar profile of custard apple-banana instant beverage mix

Treatment	Reducing sugars (%)			Non-reducing sugars (%)			Total sugars (%)		
	Initial	1 MAS	2 MAS	3 MAS	Initial	1 MAS	2 MAS	3 MAS	Initial
T ₁	3.87 ± 0.02 ^f	4.10 ± 0.03 ^f	4.42 ± 0.10 ^f	4.95 ± 0.01 ^f	10.53 ± 0.03 ^a	10.39 ± 0.03 ^a	10.10 ± 0.07 ^a	9.88 ± 0.01 ^a	15.42 ± 0.09 ^f
T ₂	3.90 ± 0.03 ^e	4.14 ± 0.02 ^e	4.44 ± 0.01 ^e	4.97 ± 0.01 ^e	10.48 ± 0.01 ^b	10.33 ± 0.02 ^b	10.04 ± 0.01 ^b	9.86 ± 0.01 ^b	15.46 ± 0.01 ^e
T ₃	3.92 ± 0.03 ^d	4.17 ± 0.01 ^d	4.47 ± 0.01 ^d	5.04 ± 0.01 ^d	10.46 ± 0.01 ^c	10.29 ± 0.03 ^c	10.00 ± 0.01 ^c	9.82 ± 0.09 ^c	15.50 ± 0.01 ^d
T ₄	3.94 ± 0.07 ^c	4.20 ± 0.03 ^c	4.50 ± 0.01 ^c	5.09 ± 0.01 ^c	10.43 ± 0.01 ^d	10.25 ± 0.03 ^d	9.96 ± 0.01 ^d	9.79 ± 0.01 ^d	15.54 ± 0.01 ^c
T ₅	3.98 ± 0.01 ^b	4.22 ± 0.04 ^b	4.50 ± 0.01 ^b	5.12 ± 0.01 ^b	10.41 ± 0.01 ^e	10.21 ± 0.03 ^e	9.95 ± 0.01 ^e	9.75 ± 0.01 ^e	15.57 ± 0.01 ^b
T ₆	3.99 ± 0.01 ^a	4.24 ± 0.09 ^a	4.54 ± 0.01 ^a	5.16 ± 0.01 ^a	10.37 ± 0.01 ^f	10.19 ± 0.07 ^f	9.91 ± 0.01 ^f	9.73 ± 0.01 ^f	15.64 ± 0.01 ^a

Values are expressed as mean ± standard deviation (n = 4). Means followed by different superscript letters within a column differ significantly at $P \leq 0.01$. MAS: months after storage.

Total sugar content increased gradually across all formulations, ranging from 15.42–15.64 % initially to 16.21–16.38 % after 90 days. The highest total sugar content was consistently observed in T₆ (15.64–16.38 %), while T₁ recorded the lowest values (15.42–16.21 %). The increase in total sugars may be attributed to the breakdown of polysaccharides and other carbohydrate fractions into soluble sugars during storage. Similar increases in total sugar content accompanied by reductions in non-reducing sugars have been reported in fruit-based beverage systems, spray-dried fruit powders and dehydrated fruit products during storage (2, 12, 22).

The observed changes in sugar composition indicate that storage-induced carbohydrate hydrolysis was the predominant biochemical reaction occurring within the beverage mix. Although these changes altered the relative distribution of sugar fractions, they remained within acceptable limits and did not adversely affect product quality. On the contrary, the moderate increase in soluble sugar content may have contributed positively to flavour perception and sweetness retention during storage, thereby supporting the sensory acceptability of the product. Similar observations have been reported in fruit-based beverage powders, where increases in soluble sugars enhanced sweetness perception without compromising product stability (2).

Sensory characteristics of the reconstituted beverage

The sensory attributes of the reconstituted custard apple-banana beverage were significantly influenced by the blending ratio of custard apple powder and banana powder as well as storage duration (Fig. 2). Although all formulations received acceptable sensory ratings throughout storage, considerable differences were observed among treatments with respect to colour and appearance, mouthfeel, aroma, taste and overall acceptability. Similar observations have been reported in fruit powder-based beverages, where formulation composition significantly influenced consumer perception and acceptance (1, 9).

Among the formulations, T₃ (10 % custard apple powder + 10 % banana powder) consistently achieved the highest sensory scores and was identified as the most acceptable formulation throughout storage. Initially, T₃ recorded the highest scores for colour and appearance (8.50), mouthfeel (8.44), taste (8.25) and overall acceptability (8.20), while maintaining superior ratings even after 90 days of storage, with corresponding scores of 8.00, 7.75, 7.80 and 7.56, respectively (Fig. 3). The enhanced sensory performance of T₃ may be attributed to the balanced contribution of both fruit powders, which provided an optimum combination of flavour, sweetness, colour and beverage consistency. The equal proportion of custard apple and banana powder produced a characteristic creamy-yellow appearance, pleasant fruit flavour and desirable mouthfeel, resulting in greater consumer preference. Similar improvements in sensory quality due to balanced fruit powder combinations have been reported in blended beverage formulations and functional drink products (2, 22).

Colour and appearance were markedly affected by the formulation composition. The superior visual quality of T₃ suggests that the balanced incorporation of banana powder contributed an attractive creamy-yellow hue without masking the characteristic appearance imparted by custard apple powder. In contrast, formulations containing excessive levels of custard apple powder, particularly T₆, received lower colour scores, declining from 7.31 initially to 6.19 after storage. The comparatively lower ratings may

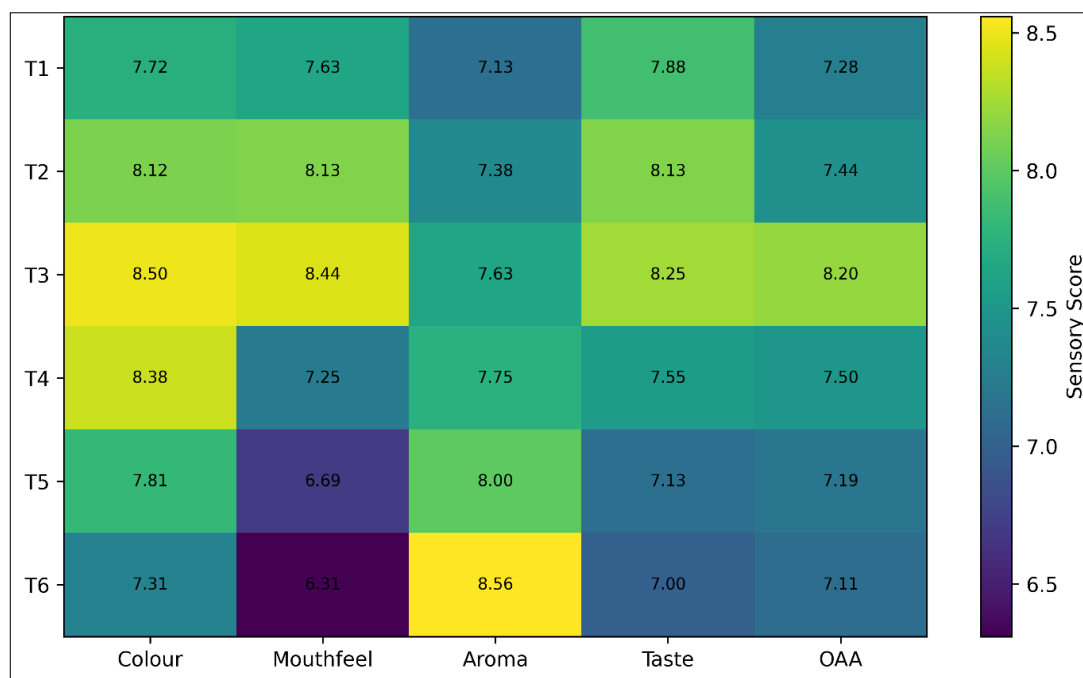


Fig. 2. Heatmap illustrating the sensory profile of custard apple-banana ready to serve (RTS) beverage formulations based on colour and appearance, mouthfeel, aroma, taste and overall acceptability at initial storage.

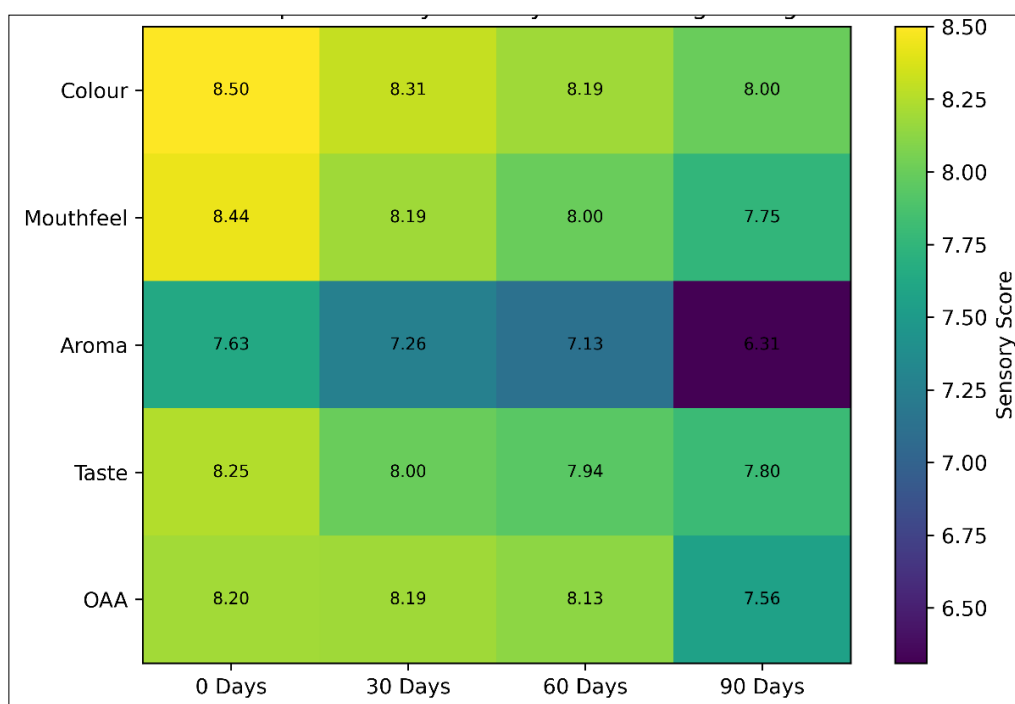


Fig. 3. Heatmap showing changes in sensory attributes of the optimised custard apple-banana ready to serve (RTS) formulation (T_3) during 90 days of ambient storage.

be associated with the darker appearance and reduced visual appeal. The gradual browning observed during storage may also be associated with non-enzymatic Maillard reactions between reducing sugars and amino compounds, potentially favoured by the observed increase in reducing sugars during storage, leading to the formation of brown-coloured melanoidins and a decline in visual acceptability. Similar effects of ingredient concentration on colour perception have been reported in fruit-based beverage systems (23, 24). The visual appearance of the reconstituted RTS beverages prepared from different custard apple and banana powder combinations is presented in Fig. 4. Distinct differences in colour intensity, opacity and overall visual appeal were observed among the formulations, corroborating the sensory evaluation results. The optimised formulation (T_3) exhibited a desirable creamy

-yellow appearance and uniform consistency, which contributed to its superior colour and appearance scores.

Mouthfeel followed a trend similar to overall acceptability, with T_3 consistently outperforming the remaining formulations. The highest mouthfeel score was observed in T_3 (8.44 initially and 7.75 after 90 days), whereas T_6 recorded the lowest values (6.31 and 5.75, respectively). The improved mouthfeel of T_3 may be attributed to the contribution of banana powder, which enhanced body, viscosity and smoothness of the reconstituted beverage. Conversely, excessive custard apple powder incorporation appeared to negatively affect beverage texture and palatability. Comparable findings have been reported in banana powder-enriched beverages, where banana solids improved texture and consumer acceptance (9, 25).

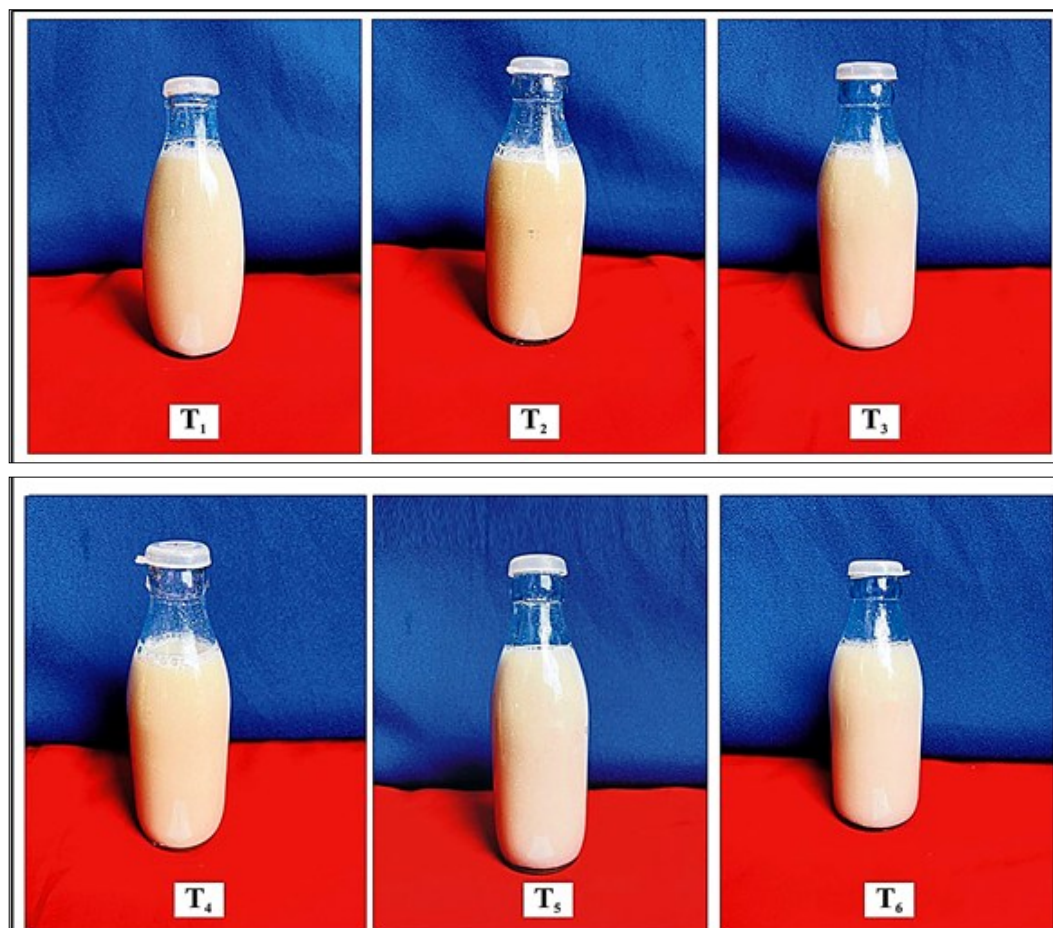


Fig. 4. Appearance of ready-to-serve (RTS) beverages prepared using different proportions of custard apple powder and banana powder.

Aroma scores increased with increasing custard apple powder concentration, reflecting the strong characteristic flavour of custard apple. The highest aroma scores were recorded in T₆ (8.56 initially and 7.88 after storage), followed by T₅, whereas T₁ exhibited the lowest values (7.13 and 6.15, respectively). While greater custard apple concentration enhanced aroma intensity, aroma alone did not determine consumer preference, indicating that a balance between aroma and other sensory attributes was necessary for overall product acceptance. Similar observations have been reported in fruit-based beverages where aroma intensity alone was insufficient to ensure overall consumer preference (1, 23).

Taste was one of the most influential attributes affecting consumer preference. The T₃ achieved the highest taste scores throughout storage, decreasing only slightly from 8.25 initially to 7.80 after 90 days. In contrast, formulations containing higher proportions of custard apple powder, particularly T₅ and T₆, received comparatively lower taste scores. The reduced acceptability of these treatments may be attributed to the stronger flavour intensity and slight astringent notes associated with higher custard apple powder incorporation. On the other hand, excessive banana powder incorporation diluted the characteristic custard apple flavour, resulting in lower sensory appeal. Therefore, the balanced flavour profile of T₃ was considered most desirable by the sensory panel. Similar findings have been reported for optimised fruit beverage formulations, where balanced flavour interactions significantly improved consumer acceptability (22).

Overall acceptability reflected the combined influence of all sensory attributes and clearly distinguished T₃ as the optimum formulation. The highest overall acceptability score was recorded in T₃ (8.20 initially and 7.56 after 90 days), whereas T₆ exhibited the

lowest values (7.11 and 6.56, respectively). Although a gradual decline in sensory scores was observed during storage across all treatments, the reduction was relatively small, indicating good retention of sensory quality under ambient conditions. Similar reductions in sensory scores during storage have been reported in fruit powder beverages and functional drink formulations, primarily due to gradual flavour and colour changes occurring over time (22, 23). The superior performance of T₃ demonstrates that an equal blend of custard apple and banana powders provided the most favourable balance between appearance, flavour, sweetness, mouthfeel and aroma, thereby maximising consumer acceptance. These findings highlight the potential of the optimised formulation for commercial development as a shelf-stable instant fruit beverage mix.

Microbial stability

The instant beverage mixes were evaluated periodically for total bacterial and fungal counts during 90 days of ambient storage. No detectable bacterial or fungal growth was observed in any of the formulations throughout the storage period, indicating excellent microbiological stability of the developed products.

The absence of microbial proliferation may be attributed to the combined effects of low moisture content, reduced water activity and protective Al laminate packaging. Water activity values in the present study remained within the range of 0.42–0.55, well below the minimum thresholds generally required for microbial proliferation in food systems approximately 0.91 for most bacteria, 0.88 for yeasts and 0.80 for moulds. This restricted range effectively limited conditions favourable for the growth of spoilage microorganisms, thereby constraining microbial metabolism and multiplication. In addition, the low-moisture environment created by dehydration significantly reduced the availability of free water

required for microbial growth, while the barrier properties of the Al laminate packaging further minimised moisture ingress and external contamination during storage. Similar observations have been reported in spray-dried fruit powders and powdered food systems, where low water activity and moisture content effectively inhibited microbial growth during storage (12, 20).

The microbiological stability observed in the present study demonstrates the effectiveness of dehydration and packaging in preserving product quality under ambient conditions. Comparable findings have been reported for spray-dried fruit products, where appropriate packaging and low-moisture conditions maintained microbiological safety throughout storage (13, 21). The results indicate that the developed custard apple-banana instant beverage mixes remained microbiologically safe for at least 90 days of storage without the need for additional preservatives, highlighting their potential for commercial production and distribution.

Economic feasibility

Economic viability is an important consideration for the successful commercialisation of value-added fruit products. Significant differences were observed among the formulations with respect to production cost, net returns and returns per rupee of expenditure (Table 4). The highest net return (₹120.50) and return per rupee of expenditure (2.52) were obtained in T₁ (5 % custard apple powder + 15 % banana powder), whereas the lowest net return (₹58.00) and return per rupee of expenditure (1.41) were recorded in T₆ (17.5 % custard apple powder + 2.5 % banana powder). The reduction in profitability with increasing custard apple powder concentration was primarily associated with the higher production cost of custard apple powder.

Although T₁ generated the highest economic returns, sensory evaluation identified T₃ (10 % custard apple powder + 10 % banana powder) as the most acceptable formulation. Importantly, T₃ also exhibited satisfactory economic performance, recording a net return of ₹95.50 and a return per rupee of expenditure of 1.91. Therefore, the optimised formulation achieved an appropriate balance between consumer acceptability, product quality, storage stability and economic feasibility.

From a commercial perspective, the findings suggest that T₃ represents the most suitable formulation for large-scale production, as it combines superior sensory attributes with acceptable profitability and excellent storage stability. Similar

studies on value-added functional beverages have emphasised that commercial success depends not only on economic returns but also on product quality, consumer acceptance and marketability (1). Consequently, the developed custard apple-banana instant beverage mix offers a promising avenue for value addition and enhanced utilisation of custard apple fruits.

Conclusion

The present study demonstrated the successful development of a shelf-stable instant beverage mix from spray-dried custard apple powder and banana powder. Formulation and storage duration significantly influenced the physicochemical and sensory characteristics, although the changes observed during 90 days of ambient storage were relatively small. All formulations remained microbiologically safe throughout storage. Among the formulations, the blend containing 10 % custard apple powder and 10 % banana powder (T₃) exhibited the most favourable balance of physicochemical stability and sensory acceptability, with desirable colour, mouthfeel, taste and overall acceptability, demonstrating the suitability of combining both fruit powders for instant beverage development. Commercially, the developed mix could enable year-round utilisation of seasonal custard apple and offer a convenient value-added product for small- and medium-scale processors, particularly in custard apple-producing regions. Its powdered form may facilitate storage, transportation and rapid beverage preparation. Future research should focus on longer shelf-life validation, retention of bioactive compounds, improved packaging systems, consumer-level sensory evaluation and pilot-scale processing to establish product consistency and commercial feasibility under practical production and distribution conditions.

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Table 4. Economic analysis of custard apple-banana instant beverage mix formulations

Particulars	Cost (₹)	T ₁	T ₂	T ₃	T ₄	T ₅	T ₆
Custard apple powder	1500/kg	37.50	56.25	75.00	93.75	112.50	126.25
Banana powder	500/kg	37.50	31.25	25.00	18.75	12.50	11.25
Citric acid	165/kg	0.50	0.50	0.50	0.50	0.50	0.50
Sugar	40/kg	1.00	1.00	1.00	1.00	1.00	1.00
Labour cost	250/day	1.00	1.00	1.00	1.00	1.00	1.00
Packaging material	3/pouch	1.00	1.00	1.00	1.00	1.00	1.00
Sub-total	-	78.50	91.00	103.50	116.00	128.50	141.00
Depreciation of equipment	-	1.00	1.00	1.00	1.00	1.00	1.00
Total cost (A)	-	79.50	92.00	104.50	117.00	129.50	142.00
Gross return (B)	-	200.00	200.00	200.00	200.00	200.00	200.00
Net return (B - A)	-	120.50	108.00	95.50	83.00	70.50	58.00
Benefit: Cost ratio (B/A)	-	2.52	2.17	1.91	1.71	1.54	1.41

Gross returns were calculated considering a selling price of ₹20 per 250 mL ready to serve (RTS) beverage. Economic calculations were performed based on the quantity of instant beverage mix required for preparation of the beverage.

Authors' contributions

S contributed to the conceptualisation, investigation, funding acquisition, preparation of the original draft manuscript, review and editing, visualisation, validation, software, formal analysis, project administration, data curation and methodology. MK and KG contributed to the methodology, validation and project administration. RTP, P and GM contributed to the supervision of the study. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

Ethical issues: None

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work, the authors used Google NotebookLM to assist in the generation and refinement of visual elements. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

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