

# Development of Shelf-Stable Instant Fruit Juice Cube & Powder

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**Abstract** - Instant fruit juice mix is a convenient and valuable product; Instant fruit juice mix was created to offer the flavor, nutrients and aroma of fresh fruits in easily consumable forms like cubes and powders. The formulations, processing and quality assessment of various instant fruit juice mixes made with drying methods like freeze drying, spray drying and foam mat drying. The primary goal is to investigate their sensory qualities, storage stability and physiochemical properties. Easy preparation, longer shelf life, less waste and year-round access to seasonal fruits is the benefits of instant fruit juice mixes. The study also examines the role of natural sweetness, stabilizers and preservatives in enhancing product quality. The findings aim to support the development of nutritious, consumer acceptable instant fruit juice mixes for both household and industrial applications in the beverage and food sectors.

**Keywords** - Instant juice mix, drying methods, shelf life, sensory quality, natural sweeteners, storage stability, convenience.

## I. INTRODUCTION

Fruits are an important part of our daily diet because they provide essential nutrients like vitamins, minerals, fiber and a wide range of health-protective bioactive compounds. Many studies highlight that regular fruit intake can help prevent lifestyle diseases and improve overall well-being (Singh *et al.*, 2018). However, the biggest challenge with fruits is their high perishability. Due to their high moisture content and rapid enzymatic activity, most fruits spoil quickly, often leading to nearly 30–40% post-harvest losses in many regions (FAO, 2020; Ratti *et al.*, 2013). This makes it difficult to store and consume them throughout the year.

Because of this problem, food scientists have focused on developing products that preserve fruits for longer periods without losing their natural goodness. One such solution is converting fruit pulp or juice into instant

powders and cubes, which has recently become popular due to its convenience, long shelf life and ease of use (Shishir & Chen, 2017). These products are generally made using different drying techniques — such as spray drying, freeze drying and foam-mat drying — which remove moisture while protecting the color, flavour and nutrients of the fruit (Cieurzyńska & Lenart, 2011; Jay *et al.*, 2000).

Instant fruit powders are especially preferred because they dissolve quickly in water, making them a fast and simple way to enjoy fruit juice anytime. They also reduce wastage, require no refrigeration, and are lighter and easier to transport as compared to fresh fruits (Horwitz *et al.*, 1980; Pui *et al.*, 2021). To get a good-quality instant powder, food technologists usually add carriers like maltodextrin, gum arabic, sugars or pectin, which help improve solubility, reduce stickiness during drying and protect sensitive nutrients like vitamin C from heat damage (Vargas *et al.*, 2024; Krishnaiah *et al.*, 2014).

Several fruits have been successfully turned into instant juice powders. For example, papaya powders made through spray or freeze drying retain their natural carotenoids and antioxidants while offering better taste and aroma (Kaur *et al.*, 2019; Chang *et al.*, 2020). Similarly, freeze-dried guava, amla and jamun powders show high levels of vitamin C, phenolics and flavonoids, giving them strong antioxidant properties and good consumer acceptance — especially jamun-based drinks (Rafiqzaman *et al.*, 2025; Lakshan *et al.*, 2019). Mango and orange powders also reconstitute very well and maintain excellent flavour quality when produced with maltodextrin and proper drying conditions (Vivek *et al.*, 2021).

Instant fruit juice cubes and powders are becoming increasingly important because they make seasonal fruits available all year round. They also help reduce

storage and transportation problems while offering consumers healthy beverage options that match today's fast-moving lifestyle (Shittu *et al.*, 2007). With consumers now showing a strong preference for natural, functional and convenient foods, instant fruit beverages fit perfectly into modern dietary expectations (Food Chemistry Reviews, 2024).

Overall, transforming fresh fruits into instant powders and cubes is not just a preservation technique, it is also a smart use of resources that reduces waste, supports sustainable food production and provides easy-to-prepare nutritious drinks. This review explores various fruits, processing techniques, quality characteristics and applications of instant fruit juice cubes, supported by current scientific research and developments in food technology.

### 1.1 Literature Review

Modern people prefer to consume feasible, easily served-up products like instant beverages using dried cubes and powders. These drinks are dried versions of commercial drinks, categorized as instant food since they require minimal rehydration. T.A. Shittu *et al.* (2007)

### 1.2 Papaya Fruit Powder

Papaya (*Carica papaya* L.), belonging to the family Caricaceae, originated in Central America and is now cultivated widely across tropical regions such as India, Brazil, and Southeast Asia (Kaur *et al.*, 2019).

It is valued for its high antioxidant, phytochemical, and nutrient content that contributes to both nutritional and medicinal benefits (Vij & Prashar, 2015). Papaya exhibits anticancer, anti-inflammatory, hepatoprotective, and antimicrobial properties due to bioactive compounds including papain and flavonoids (Mahendran *et al.*, 2021). Regular consumption of lycopene-rich papaya correlates with significantly reduced prostate cancer risk (Yogiraj *et al.*, 2014). The rich fiber content in papaya aids digestion and prevents colon cancer through toxin binding and antioxidant protection (Ali *et al.*, 2011). The enzymes papain and chymopapain in papaya possess strong anti-inflammatory effects beneficial for arthritis and wound healing (Pandey *et al.*, 2016; Owoyele *et al.*, 2008).

However, due to its soft texture and 88% moisture, papaya is highly perishable and suffers substantial post-harvest losses during handling (Shivani *et al.*, 2020).

Drying methods such as spray-drying or freeze-drying preserve nutritional quality while converting papaya into a stable powder suitable for beverages and supplements (Pakalwad *et al.*, 2010). Global papaya production continues to grow, especially in India, driven by demand for tropical fruits and health-oriented food products (Evans & Ballen, 2012).

Despite abundance, Malaysian papaya commercialization remains limited due to bitterness and odor, prompting formulation-based improvements (Badsha *et al.*, 2020). The study developed six formulations of papaya drink mix combining papaya powder, milk, fructose, carrageenan, and vanilla. Only papaya proportions (12.5–28.7%) were varied, following protocols adapted from Vennila *et al.* (2020). Sensory evaluation by 30 panelists identified Sample 3 (23% papaya) as most preferred for its mild flavor, smooth texture, and balanced sweetness (Chang *et al.*, 2020).

Sample 1, with higher papaya concentration, exhibited bitterness and enzymatic aroma, reducing its acceptability (Lakshan *et al.*, 2019). Physical analysis showed water activity between 0.355–0.369, below the USDA's 0.85 safety threshold, ensuring storage stability (Calvacanti *et al.*, 2006).

Total soluble solids ranged from 15.9–16.7 °Brix, signifying ideal sweetness.

pH values (6.44–6.50) indicated mildly acidic conditions due to citric acid from papaya, consistent with dairy beverages. Color uniformity ( $\Delta E < 1.0$ ) confirmed visually stable formulation (Wojciech & Maciej, 2011). Sample 3's proximate composition was moisture 5.3%, protein 12.6%, fat 0.3%, ash 4.1%, fiber 0.2%, carbohydrate 77.7% — higher protein and carbohydrate but lower fat than commercial papaya milk (Raja *et al.*, 2019; Hayes, 2020). Microbial analysis recorded  $7.3 \times 10^3$  CFU/g with negligible coliform, compliant with Malaysian Food Regulations

(1985) and safe for consumption (Pauter *et al.*, 2018). The optimized formulation, containing 23% papaya powder, 40% milk powder, and 28% fructose, demonstrated superior sensory, nutritional, and microbial safety performance.

Hence, powdered papaya drink mixes offer a convenient, health-promoting, and commercially viable solution for reducing fruit wastage while enhancing

functional beverage innovation (Farzana & Mohajan, 2015).

### 1.3 Guava Amla and Jamun Fruit Powder

Freeze-dried instant juice powder production from guava, amla, and jamun is gradually becoming an effective approach to making fruit nutrients available throughout the year in a stable and convenient form. Freeze-drying is a preferred method of dehydration in that it preserves the nutritional value, flavor, and color of the food materials better compared with other drying procedures (Singh *et al.*, 2018; Sharma *et al.*, 2020). In this study, three formulations were developed and tested with regard to their physicochemical, bioactive, and sensory characteristics: GJP, AJP, and JJP (Rafiquzzaman *et al.*, 2025). In addition, the powders proved to be highly stable, retaining key nutrients like vitamin C (116.21–176.89  $\mu\text{M}$ ),  $\beta$ -carotene (5.09–8.03  $\mu\text{M}$ ), phenolics (289.56–822.62 mg GAE/100 g), flavonoids (98.21–607.74 mg QE/100 g), and antioxidant activity (43.05–45.90  $\mu\text{M}$  Trolox equivalents), indicating that they have potential to serve as functional food ingredients (Ahmed *et al.*, 2021; Rafiquzzaman *et al.*, 2025). All powders were well accepted during sensory evaluation; jamun powder scored the highest preference 8.29, followed by guava 7.97 and amla 7.74, indicating more preference for jamun-based drinks. Kumari *et al.*, 2019; Rafiquzzaman *et al.*, 2025

In the last few years, people have become more health-oriented and seek foods that are nutritious, convenient, and natural. According to Statista *et al.* (2024), the global functional food market will reach over USD 267 billion by 2027, hence encouraging innovation in fruit-based functional products. Although fruits are naturally rich in vitamins, minerals, and antioxidants, their high moisture content tends to cause fast spoilage, leading to 40–50% post-harvest losses. Fruit processing Preparing instant fruit powders reduces the level of moisture and water activity, thereby enhancing shelf life and facilitating transportation and utilization. Conventional drying methods consist of sun drying, tray drying, and spray drying. These techniques generally expose fruits at higher temperatures, resulting in nutrient losses and discoloration of the product (Sharma *et al.*, 2020; Patel *et al.*, 2022). Freeze-drying, on the other hand, removes water through sublimation at low temperatures, thus protecting heat-sensitive compounds and preserving texture and color (Ahmed *et al.*, 2021; Singh *et al.*,

2018). Freeze-drying has already proved to be successful with fruits such as mango, papaya, strawberry, acerola, and guava, as it retains flavor, bioactives, and overall quality (Kumar *et al.*, 2017; Patel *et al.*, 2022). Every variety of fruit picked up has its nutritional profile: guava, being rich in vitamin C and dietary fiber; amla, a good antioxidant source with medicinal values; and jamun, rich in anthocyanin and phenolic compounds (Devi *et al.*, 2019; Kumari *et al.*, 2019). However, all three are highly perishable and available only during specific seasons, limiting their year-round use (Siddiqui *et al.*, 2021).

Freeze-drying them into instant juice powders ensures continuous availability while maintaining their nutritional integrity and sensory appeal (Rafiquzzaman *et al.*, 2025). Among the tested powders, jamun powder had the highest sensory and nutritional rating; thus, it has strong potential for commercialization in functional food and beverage industries. Kumari *et al.* (2019); Rafiquzzaman *et al.* (2025) Overall, the development of freeze-dried guava, amla, and jamun powders represents a sustainable solution to minimize fruit wastage, support convenient nutrition, and meet the demands of modern consumers for healthy ready-to-use beverages (Chen *et al.*, 2023; Patel *et al.*, 2022).



Raw Fruit Powders (Freeze-Dried), Formulated And Reconstituted Juice Sample

Source: Rafiquzzaman *et al.* (2025)

### 1.4 Instant Probiotic Fruit Powder

Fresh and fully ripe fruits such as apple (*Malus domestica*), grape (*Vitis vinifera*), mango (*Mangifera indica*), orange (*Citrus sinensis*), and sapota (*Manilkara zapota*) were procured from different local markets on the same day of processing to ensure freshness and

uniform maturity. Fruits were cleaned to remove the damaged and overripe ones, washed in running potable water to remove adhering dirt and surface impurities, peeled, deseeded, and cut into small uniform pieces in order to have proper drying. Prepared fruit samples were dried using two different methods: solar drying and hot air oven drying up to a constant weight. Among the fruits, grapes took more time due to their thick seed coat and waxy surface, showing a reduced rate of moisture loss, as already reported by Fava *et al.* (2011) and Tarhan *et al.* (2010).

Dried fruit pieces were ground into fine powder with the help of a mechanical grinder. The obtained powders were sieved through a 60-mesh sieve for uniformity and packed in airtight glass jars to prevent reabsorption of moisture or microbial contaminations. Fruit powders were prepared according to Mounika *et al.* (2021), following the standard procedures to maintain homogeneity for further analyses and product formulation. Proximate composition, including moisture, protein, fat, ash, carbohydrate, and calcium contents, was analyzed according to AOAC (2012) methods; whereas carbohydrates were estimated by the anthrone method described by Hedge *et al.* (2013), and mineral analysis was carried out according to Raghuramulu *et al.* (2012). Dried fruit powders were tested for their microbial quality by standard plate count methods, as recommended by Adegoke *et al.* (2014) and Hasanuzzaman *et al.* (2014), showing that all samples were within the microbiological limits of ISO (2018) concerning food safety. For sensory evaluation, one gram of each fruit powder was reconstituted in ten milliliters of potable water and evaluated by a trained sensory panel using the nine-point hedonic scale method described by Meilgaard *et al.* (2013). The final five formulations for each drying method were prepared based on the sensory attributes of taste, aroma, color, and overall acceptability, and the most preferred formulations, namely F5 from the hot air oven and F4 from the solar dryer, were selected for probiotic enrichment by following the process suggested by Basavaraj *et al.* (2018). The probiotic strain *Lactobacillus casei* Shirota was isolated from a commercial Yakult® probiotic beverage, purified, and grown in sterilized skim milk at 37 °C for 24 hours according to Nagpal *et al.* (2012).

The probiotic culture was standardized using a plate count method and harvested by centrifugation at 5000 rpm for 15 minutes under aseptic conditions. The

concentrated probiotic biomass was mixed into the selected fruit powder formulations in order to obtain approximately  $1 \times 10^7$  CFU per 50 g of product and air-dried under sterile conditions at room temperature to avoid loss of viability of the probiotics. The final probiotic-enriched fruit powders were then packed in laminated pouches and stored under refrigeration. The proximate, microbial, and sensory analyses were repeated after the incorporation of probiotic, and the results indicated that the addition of *L. casei* Shirota did not alter the nutritional composition or the sensory acceptance of the fruit powders but rather enhanced their functional quality and probiotic potential, matching the conclusion drawn by Vasudha *et al.* (2013) and Patel *et al.* (2017).

The overall study confirmed that instant probiotic fruit powders could be successfully developed using solar and hot air drying methods with nutritional, sensory, and microbial stability intact for functional food applications and round-the-year consumption. Fresh and fully ripe fruits such as apple (*Malus domestica*), grape (*Vitis vinifera*), mango (*Mangifera indica*), orange (*Citrus sinensis*), and sapota (*Manilkara zapota*) were procured from different local markets on the same day of processing to ensure freshness and uniform maturity. Fruits were cleaned to remove the damaged and overripe ones, washed in running potable water to remove adhering dirt and surface impurities, peeled, deseeded, and cut into small uniform pieces in order to have proper drying. Prepared fruit samples were dried using two different methods: solar drying and hot air oven drying up to a constant weight. Among the fruits, grapes took more time due to their thick seed coat and waxy surface, showing a reduced rate of moisture loss, as already reported by Fava *et al.* (2011) and Tarhan *et al.* (2010). Dried fruit pieces were ground into fine powder with the help of a mechanical grinder. The obtained powders were sieved through a 60-mesh sieve for uniformity and packed in airtight glass jars to prevent reabsorption of moisture or microbial contaminations. Fruit powders were prepared according to Mounika *et al.* (2021), following the standard procedures to maintain homogeneity for further analyses and product formulation. Proximate composition, including moisture, protein, fat, ash, carbohydrate, and calcium contents, was analyzed according to AOAC (2012) methods; whereas carbohydrates were estimated by the anthrone method described by Hedge *et al.* (2013), and mineral analysis

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### 1.5 Instant Mango Juice Powder

Ripe mango fruits (*Mangifera indica* L.) were procured from local markets, washed thoroughly under running tap water to remove adhering dust and surface impurities, then sorted to eliminate overripe or damaged fruits. The fruits were peeled, trimmed, and cut into small pieces to facilitate efficient juice extraction. Juice was extracted using a mechanical extractor, and the remaining fruit pomace was re-extracted with potable water and recombined to maximize pulp yield, following the general approach described by Kumar *et al.* (2015) and Rathore *et al.* (2016). The extracted pulp was treated with an increased preservative concentration to enhance microbial stability, and its initial soluble solid content was adjusted to 20.5–25° Brix to maintain uniform sweetness and flavor, similar to the methods followed by Devi *et al.* (2018). The pulp was then concentrated using a climbing film evaporator to reach a final concentration of 40° Brix, while the early condensate was collected and reintroduced to the concentrate to restore volatile flavor compounds lost during evaporation, as suggested by Singh *et al.* (2014). To improve the drying characteristics and enhance powder stability, powdered sugar, dextrose, maltodextrin, and food-grade color were blended into the concentrated pulp, along with flavor adsorbents for aroma retention. Maltodextrin and tricalcium phosphate were incorporated at 0.093 kg/kg pulp and 0.015 kg/kg solids, respectively, acting as anti-caking and free-flowing agents, in accordance with the recommendations of Jaya *et al.* (2010) and Deshmukh *et al.* (2019). The prepared mango pulp mixture was spread uniformly in stainless-steel trays at a loading rate of approximately 1.5 kg per tray with a layer thickness of about 1.2 cm and dried in a cabinet dryer at 55 °C for 2 hours followed by 70 °C overnight to achieve an optimal moisture level. The semi-dried product was ground to fine powder, mixed again with tricalcium phosphate and a small amount of citric acid to balance acidity and prevent clumping, then reground to obtain a uniform mesh size suitable for instant beverage preparation, following the general recommendations of Bhusari *et al.* (2014) and Lakshmi *et al.* (2020).

The powdered mango juice was packaged in air-tight laminated plastic and amber-colored glass containers under controlled conditions to protect it from light and humidity, ensuring better shelflife and stability, as

supported by Rahman *et al.* (2021). Moisture content was determined by vacuum drying at  $70 \pm 1$  °C for six hours under 100 mmHg using AOAC (2012) methods, while other proximate parameters such as ash, crude protein, and fat were determined following standard AOAC analytical techniques. Ascorbic acid was estimated by the 2,6-dichlorophenol indophenol titration method as described by Bessy *et al.* (2013), and total and reducing sugars were determined using the Lane-Eynon titrimetric method according to Ranganna *et al.* (2014). The proximate composition of the instant mango juice powder showed 3.0 % moisture, 0.8 % ash, 1.4 % protein, 0.9 % fat, 3.8 % acidity, 14.3 mg/100 g ascorbic acid, 61.5 % total sugars, and 9.3 % reducing sugars. Upon reconstitution, the beverage exhibited 3.6 mg/100 mL vitamin C, indicating slight losses attributed to oxidative degradation during drying and storage, consistent with reports by Singh *et al.* (2020). Comparative sensory evaluation with commercially available mango beverages revealed that the instant mango juice powder was nutritionally sound, organoleptically acceptable, and in some parameters superior to commercial bottled juice products, aligning with the observations of Patil *et al.* (2017) and Ghosh *et al.* (2022). Overall, the developed instant mango juice powder demonstrated excellent solubility, flavor retention, and consumer acceptance, suggesting its potential for large-scale production as a convenient, nutrient-rich beverage alternative.

### 1.6 Instant Orange Juice Powder

Freshly harvested orange fruits were sorted to remove damaged or overripe ones, washed under running water, and cut into halves for juice extraction. The juice was extracted manually using a reamer-type extractor to preserve the natural flavor and aroma and then filtered through fine muslin cloth to remove coarse pulp and seeds. The extracted juice was divided into treatments to evaluate the effect of albumin and carboxymethyl cellulose (CMC) as stabilizing and foaming agents. The control treatment was fresh juice with 12% total soluble solids (TSS), while other formulations included combinations of 0.8% or 1% albumin with sucrose adjustments to 12%, 13.5%, or 16% TSS. Additional formulations contained 0.5% or 1% CMC with albumin at corresponding TSS levels. The methodology followed the approaches of Raghavi *et al.* (2018) and Alavi *et al.* (2020). Each treatment

was homogenized and concentrated under controlled conditions.

Five levels of juice concentration were prepared. The first was concentrated to 20% TSS using a rotary evaporator at 40 °C under vacuum (28 in. Hg) to minimize flavor loss. The second was reduced to 16% TSS, then sweetened with sucrose to reach 20%. The third and fourth were concentrated to 30% and 26% TSS, respectively, and adjusted with sucrose to 30%, while the fifth was concentrated directly to 40% TSS. To enhance foam structure and powder stability, 1.5% spray-dried egg albumin was added to all concentrated samples before drying, following Tiwari *et al.* (2017). The mixtures were whipped in a Hobart mixer for 5 minutes until a uniform foam—approximately triple in volume was obtained. The foamed samples were spread as thin layers on paraffin-coated stainless-steel trays and dried in a hot-air oven at 60 °C until they became brittle, as described by Singh *et al.* (2014) and Dhingra *et al.* (2019). The dried flakes were finely ground to produce uniform orange juice powder with about 3% moisture.

Physicochemical analyses were performed following AOAC (2012) methods, including determination of moisture, ash, total sugars, reducing and non-reducing sugars, acidity, and pH. Total soluble solids and refractive index were measured with a digital refractometer, while color intensity was evaluated spectrophotometrically at 420 nm (Sharma *et al.*, 2015). Ascorbic acid was quantified using the 2,6-dichlorophenol indophenol titration method (Patel *et al.*, 2016). Calcium and potassium contents were determined by atomic absorption spectrophotometry after dry ashing (Mehta *et al.*, 2018). Viscosity was assessed using a Brookfield viscometer with spindle No. 3 at variable speeds to evaluate the effect of drying and additives on flow behavior (Sahu *et al.*, 2021).

For sensory evaluation, the reconstituted orange juice powders were diluted to 14% TSS and assessed for color, flavor, taste, and overall acceptability by a ten-member trained panel using a 9-point hedonic scale (Meilgaard *et al.*, 2013). Data were statistically analyzed by ANOVA following Chatterjee *et al.* (2014). Among all treatments, the sample containing 1% albumin and 0.5% CMC achieved the best sensory scores, with bright orange color, fresh aroma, smooth texture, and excellent solubility. The reconstituted beverage had an ascorbic acid content of 35.6 mg/100 mL, showing only slight loss compared to fresh juice,

consistent with findings of Nwachukwu *et al.* (2020) and Dhanasekaran *et al.* (2022). The study demonstrated that incorporating suitable stabilizers like albumin and CMC before drying improved foam stability, nutrient retention, and sensory quality, producing a shelf-stable and easily reconstitutable instant orange juice powder.

### 1.7 Bael Fruit Powder

Fully ripe bael fruits (*Aegle marmelos* L. Corr.) of a local cultivar were collected, graded, and thoroughly washed to remove surface impurities. The pulp, including seeds and fibers, was extracted manually and mixed with water in a 1:0.75 (w/v) ratio to obtain a smooth consistency.

To enhance color and flavor stability during dehydration, citric acid (5 g/kg pulp) and sodium bicarbonate (2 g/kg pulp) were incorporated, following the approach of Borse *et al.* (2018) and Patel *et al.* (2020). The prepared pulp mixture was spread uniformly on stainless steel trays and dried under controlled sunlight until complete dehydration occurred. The dried material was ground using a mixer grinder (Singer MG-46 model) and sieved through a 150  $\mu\text{m}$  mesh to obtain uniform fine powder. Separately, dehydrated lime and ginger were pulverized and sieved to the same fineness. Commercial-grade vanilla powder (Nanjin MSN Chemical Co. Ltd., China) was also included as a flavoring agent. The bael fruit powder was blended with sugar and the flavoring components (powdered lime, vanilla, and ginger) in different ratios to prepare three instant drink formulations. Each formulation was reconstituted in water (1:5, w/v) and stored at ambient conditions ( $30 \pm 2$  °C;  $70 \pm 3\%$  RH) for 42 days, as adapted from methods of Dhanasekaran *et al.* (2022) and Raj *et al.* (2023).

The proximate composition—moisture, crude protein, and crude fat—was analyzed in triplicate following AOAC (2016) standard procedures. Water activity ( $a_p$ ) was determined using a Labstar aw meter (Lachen, Switzerland), while color attributes ( $L^*$ ,  $a^*$ ,  $b^*$ ) were measured with a Konica Minolta CR-400 colorimeter, where  $L^*$  indicates lightness,  $a^*$  redness/greenness, and  $b^*$  yellowness/blueness (Kumar *et al.*, 2017). Total soluble solids (TSS) were recorded using a digital refractometer (ATAGO HR-5, Japan) and expressed in °Brix. Titratable acidity was determined by the volumetric method described by Horwitz and

Latimer (2012), and pH was measured using a calibrated digital pH meter (Model 9157 BN, England). Microbial load (total plate count, CFU/g) was assessed following AOAC (2016) protocols. For sensory analysis, reconstituted drinks (1:5 ratio) were evaluated by trained panelists for color, aroma, taste, and overall acceptability using a five-point hedonic scale (Meilgaard *et al.*, 2013).

All analyses were performed in triplicate, and data were statistically treated under a Completely Randomized Design (CRD) using ANOVA (Sahu *et al.*, 2021). Mean separation was conducted using the Least Significant Difference (LSD) test at  $\alpha = 0.05$ , while non-parametric data were subjected to the Friedman test via MINITAB software (Gupta *et al.*, 2020).

During the 42-day storage period, physicochemical and microbial parameters showed gradual but controlled variation. The moisture content of instant drink powders increased slightly from 7.10% to 7.60%, consistent with the observations of Senapati *et al.* (2019). Among treatments, the lime-flavored sample (T3) exhibited minimal change (final moisture 7.29%), aligning with the Sri Lankan Standard (SLS 401:2012) for tea extract powders (<7% moisture). The fat content was highest (1%) in the ginger-based formulation (T1), attributable to the natural oil content of ginger (Sarkar *et al.*, 2021). Protein content ranged from 16.2% to 19.8%, showing nutritional adequacy. Water activity remained below 0.60 in all samples, confirming product stability and microbial safety (Bandyopadhyay *et al.*, 2022). The lowest  $a_p$  (0.57) was recorded in T1, confirming the dehydrated product's stability. Microbial counts remained within permissible limits throughout storage, suggesting effective dehydration and hygienic handling.

The reconstituted instant drinks exhibited total soluble solids between 5.0–5.2 °Brix, titratable acidity from 0.13–0.19%, and a stable pH around 4.35–4.36. Color analysis revealed  $b^*$  values around 9.9, indicating an appealing yellowish tone typical of bael-based beverages. Sensory evaluation results showed that formulations containing ginger (T1) and lime (T3) scored significantly higher ( $p < 0.05$ ) for aroma, color, and taste than the vanilla variant (T2), with mean scores corresponding to “like very much.” The combination of bael, ginger, and lime produced superior overall acceptability, consistent with findings

of Nwachukwu *et al.* (2020) and Priyadarshini *et al.* (2024).

The study thus demonstrated that bael-based instant drink powders formulated with natural flavor enhancers such as ginger and lime maintained

excellent physicochemical quality, microbial safety, and sensory appeal during storage. These formulations have strong potential for development as shelf-stable, consumer-acceptable, and nutritionally beneficial natural beverage powders

Comparative Table: Drying Methods and Quality Characteristics

DRYING METHOD	TEMPERATURE RANGE	NUTRIENT RETENTION	COST	SHELF LIFE	SENDORY QUALITY
Freeze Drying	-40°C to -60°C	Excellent (90–95%)	High	Long	Excellent
Spray Drying	150°C–200°C	Moderate (70–80%)	Medium	Medium	Good
Foam Mat Drying	50°C–70°C	Good (80–85%)	Low	Long	Excellent

Source: (Shishir *et al.*,2017)

## II.CONCLUSION

Instant fruit juice cubes and powders represent a sustainable innovation in the food industry, providing convenience, nutrition, and extended shelf life. Among the evaluated methods, freeze drying ensures maximum nutrient preservation, while foam mat drying offers economic advantages and better reconstitution. Additives such as maltodextrin, citric acid, and natural flavoring agents play a key role in improving product quality. These instant beverages provide a viable solution to reduce post-harvest losses and promote the utilization of tropical fruits. Future research should focus on probiotic fortification, natural fortifiers, and eco-friendly packaging to enhance the commercial potential of instant fruit juice cubes (Singh *et al.*, 2018; FAO, 2020; Mahendran *et al.*, 2021).

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