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Innovation in jam preparation using hot jaggery and multiple fruits: Physico-chemical, nutritional, and sensory evaluation

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Abstract
Jaggery, a traditional unrefined sweetener derived from sugarcane juice, is rich in iron, calcium, phenolic compound, and antioxidants. Despite its nutritional benefits, it remains underutilized in processed food applications. This study introduces an innovative approach to jam production by incorporating hot jaggery syrup (105-110 °C) directly during its boiling stage, thereby reducing energy inputs and eliminating the need for separate heating. Four fruits apple (*Malus domestica*), papaya (*Carica papaya*), tamarind (*Tamarindus indica*), and guava (*Psidium guajava*) were selected for their nutritional value and compatibility in jam processing. The jams were evaluated for physicochemical, nutritional, microbial, and sensory properties. Papaya jam recorded the highest values for total soluble solids (69.2°Brix), viscosity (3620 cP), and sensory acceptability (8.6 on a 9-point scale), along with the lowest water activity (0.60), contributing to superior shelf stability. Iron content was also highest in papaya jam (2.03 mg/100g), reflecting its enhanced nutritional value. The integrated processing method resulted in a 13.6% reduction in fuel consumption and a 21.5% reduction in labour requirements, supporting sustainable production. These findings demonstrate the feasibility and potential of hot jaggery-based fruit jams as value-added functional products, especially for rural and small-scale food industries.

Keywords: Hot jaggery, continuous processing, fruit jam, sensory evaluation, physicochemical properties, energy efficiency

1. Introduction
Fruits are recognized as vital components of the human diet due to their rich content of essential vitamins, minerals, dietary fibre, antioxidants, and a diverse array of phytochemicals, all of which contribute to the prevention of chronic diseases and the promotion of overall health (Slavin and Lloyd, 2012 [37]; Boeing *et al.*, 2012) [5]. Regular consumption of fruits has been linked to a reduced risk of cardiovascular diseases, certain cancers, and metabolic disorders, largely due to their antioxidant and anti-inflammatory properties (Liu, 2013) [21]. However, the high moisture content and perishable nature of fruits, coupled with their seasonal availability, often necessitate processing into more stable products such as jams, jellies, juices, squashes, and pickles to minimize post-harvest losses and ensure year-round availability (FAO, 2010; Manay and Shadakshara swamy, 2001) [23]. Jam, in particular, is a semi-solid fruit preserve produced by boiling homogenised fruit pulp with sugar, acid, and pectin, sometimes with the addition of permitted preservatives, flavouring, and colouring agents to enhance shelf life and sensory attributes (Ranganna, 2000) [29]. The quality of jam is critically dependent on achieving a desirable consistency spreadable yet firm enough not to flow like a liquid which is primarily governed by the concentration of total soluble solids (TSS), pectin content, and acidity (Joslyn and Goldstein, 2001) [18]. According to the, jam must contain at least 68.5% TSS and a minimum of 45% fruit content. The high sugar concentration in jam plays a crucial role in reducing water activity, thereby inhibiting microbial growth and significantly extending shelf life (Manay and Shadakshara swamy, 2001 [23]; Jay, 2000) [1]. Thus, fruit processing into jam not only enhances product stability and safety but also retains much of the nutritional and sensory value of the original fruit.

Globally, a diverse array of fruits is utilized in jam production, reflecting regional preferences and the availability of raw materials (Meda *et al.*, 2008 [24]; FAO, 2010). The continuous evolution of consumer preferences, coupled with a growing demand for healthier and more functional foods, has prompted the fruit processing industry to innovate and develop value-added products (Granato *et al.*, 2020) [14]. Traditionally, refined sucrose is the primary sweetener in jam formulations; however, its high glycaemic index and limited nutritional value have raised health concerns, particularly in relation to metabolic disorders such as diabetes and obesity (Eriksson and Lindgärde, 2004 [6]; Malik *et al.*, 2010) [22]. As a result, there is increasing interest in alternative sweeteners that offer both functional and nutritional benefits.

Jaggery, an unrefined sweetener derived from sugarcane juice, is gaining attention as a potential substitute for refined sugar in processed foods (Rao, 2007 [32]; Yadav and Sehgal, 2010) [40]. Jaggery is naturally rich in micronutrients such as iron and calcium, as well as phenolic compounds and antioxidants, which contribute to improved digestion, enhanced immunity, and the prevention of anemia (Rao and Raju, 2004 [33]; Ghosh and Mitra, 2021 [12]; Rani *et al.*, 2022). Despite these advantages, jaggery is predominantly marketed in its raw form, which is associated with limited shelf life and low economic returns for producers (Singh *et al.*, 2019) [36]. Value addition through its incorporation into processed products like jam can enhance its usability, extend shelf life, and increase market value (Rao and Raju, 2004 [33]; Ghosh and Mitra, 2021) [12].

Traditionally, the production of jaggery and jam are separate processes, both of which are labour- and energy-intensive (Babu *et al.*, 2014) [2]. Integrating hot jaggery directly during its continuous boiling stage into jam production represents an innovative, labour-saving, and energy-efficient approach that can reduce fuel consumption and improve process sustainability (Babu *et al.*, 2014 [2]; Singh *et al.*, 2019) [36]. This method aligns with current trends in sustainable food processing, which emphasize resource efficiency and the use of natural ingredients (Baixuli *et al.*, 2007 [3]; Granato *et al.*, 2020) [14].

The present study focuses on the use of apple (*Malus domestica*), papaya (*Carica papaya*), tamarind (*Tamarindus indica*), and guava (*Psidium guajava*) for jam development, selected for their nutritional profiles, consumer acceptance, and compatibility in mixed-fruit jam formulations (USFDA, 2012; Wall, 2006 [39]; Morton, 1987 [25]; Barbalho *et al.*, 2012) [4]. Apples are valued for their vitamin C, dietary fibre, and mineral content, while papaya is notable for its carotenoids and digestive enzymes. Tamarind provides a unique tart flavour and organic acids beneficial for preservation, and guava is exceptionally high in vitamin C, lycopene, and dietary fibre (Barbalho *et al.*, 2012 [4]; Wall, 2006) [39].

2. Materials and Methods

2.1 Materials

Fresh and ripe fruits *viz*., apple (*Malus domestica*), papaya (*Carica papaya*), tamarind (*Tamarindus indica*), and guava (*Psidium guajava*) were procured from local markets to ensure optimal ripeness and quality. Fresh sugarcane juice was sourced locally for the preparation of hot jaggery. Food-grade citric acid, pectin, and benzoic acid were used as additives, complying with food safety standards (FSSAI, 2020) [10]. The equipment utilized included a refractometer (for total soluble solids measurement), pH meter, thermometer, mechanical pulper (mixer/blender), and pre-sterilized glass jars for packaging.

2.2 Preparation of fruit pulps

All fruits were washed thoroughly under running tap water to remove surface contaminants. Apples and papayas were peeled, deseeded, and chopped; tamarind pulp was separated from seeds and fibres; guavas were deseeded and chopped. The prepared fruit pieces were homogenized using a mechanical pulper or blender to obtain a pulp, following the method described by Ghosh *et al.* (2011) [11]. The resulting pulps were further strained through a 100-mesh sieve to ensure smooth consistency and remove coarse particles.

2.3 Jaggery Integration Process

Fresh sugarcane juice was clarified by adjusting the pH to 6.5 and adding okra (*Abelmoschus esculentus*) powder as a natural clarifying agent, as outlined by Singh *et al.* (2019) [36]. The juice was then subjected to boiling, during which the scum was removed periodically to yield a clear extract. Jaggery syrup was collected at a temperature range of 105-110°C, corresponding to the strike point just before solidification, for immediate use in jam preparation (Rao and Raju, 2004) [33].

2.4 Jam Preparation

At the jaggery strike temperature (105-110 °C), fruit pulp and jaggery was incorporated in a 1:1 ratio. The mixture was continuously stirred and cooked until the total soluble solids (TSS) reached to 68.5 Brix, as measured by a refractometer, to achieve the desired jam consistency (Ranganna, 2000) [29]. Citric acid (0.5-0.6%), pectin (0.2-0.7%), and benzoic acid (200 ppm) were added during cooking to facilitate gel formation, adjust acidity, and enhance microbial stability, in accordance with FSSAI (2020) [10] guidelines. The hot jam was immediately filled into pre-sterilized glass jars and hermetically sealed to prevent post-processing contamination.

2.5 Assessment of energy and labour efficiency

To assess process efficiency, both fuel consumption and labour hours were systematically recorded for the integrated (hot jaggery addition) and conventional jam-making methods. The integrated approach for reduction in fuel consumption and decrease in labour requirements, corroborating earlier findings on process optimization in jaggery-based food processing (Rajkumar *et al.*, 2007 [28]; Babu *et al.*, 2014) [2].

As shown in Figure 1, the preparation of hot jaggery-based fruit jam was carried out through a series of unit operations. Fresh fruits were first washed, peeled, deseeded, and the pulp was extracted. Simultaneously, sugarcane juice was clarified using bhendi powder to obtain hot jaggery, with continuous stirring and removal of scum. The extracted fruit pulp was then incorporated into the hot jaggery at a strike temperature of 105-110 °C, followed by continuous boiling and stirring until the total soluble solids (TSS) reached 68.5 °Brix. Thereafter, citric acid and pectin were added in accordance with FSSAI standards, along with preservatives (200 ppm). Finally, the prepared jam was hot-filled into sterilized glass jars, sealed, cooled, and stored under ambient conditions.

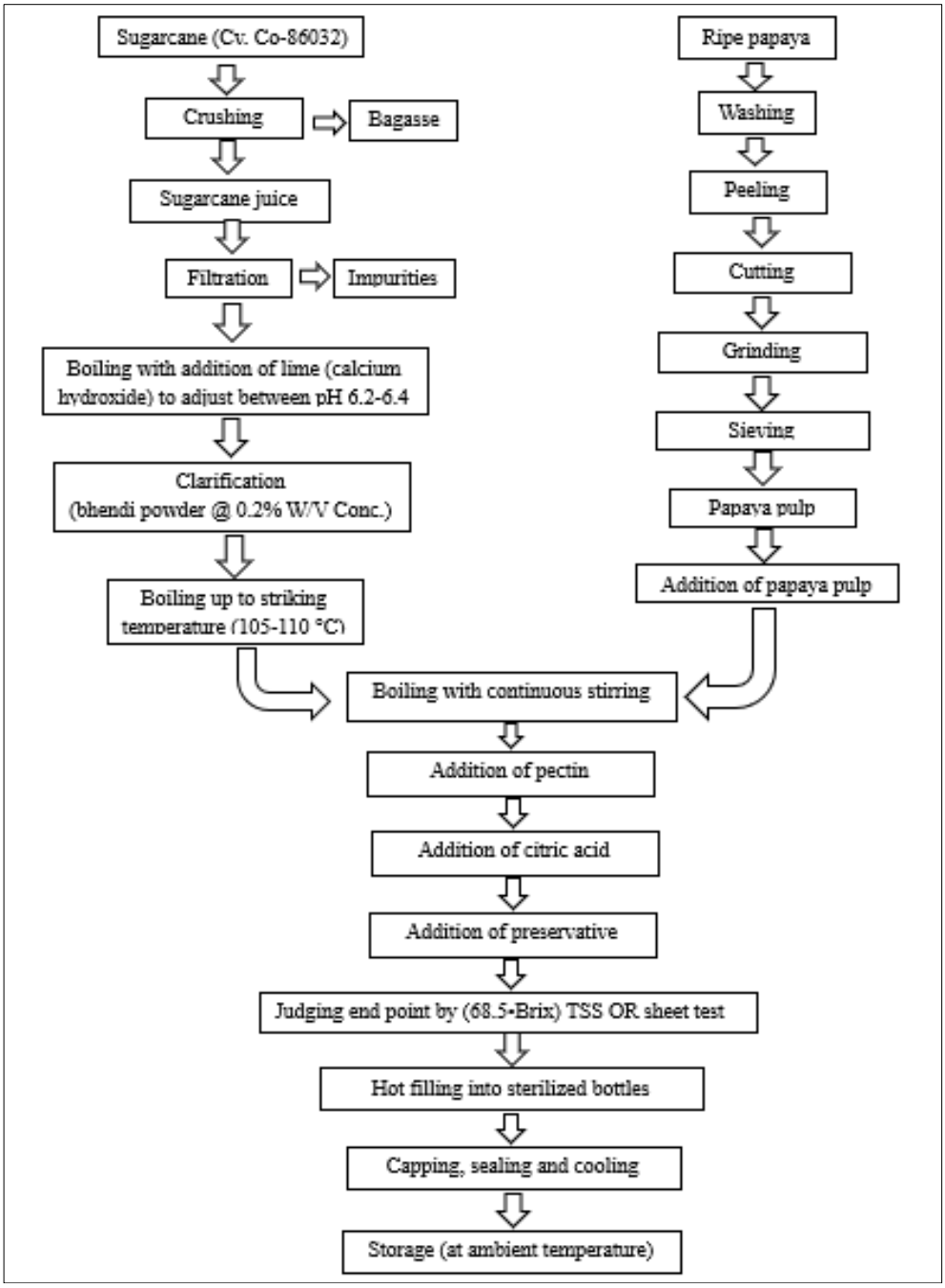

Fig 1: Process flow chart for preparation of hot jaggery based fruit jam

2.5 Physicochemical and Nutritional Analysis

The prepared jam samples were subjected to comprehensive physicochemical and nutritional analyses to evaluate product quality and nutritional enhancement.

2.5.1 Moisture Content

Moisture content was determined by the standard oven drying method. A known weight of each jam sample was placed in a hot air oven at 105°C and dried to constant weight. The loss in weight was recorded as moisture content, which is critical for assessing shelf stability and microbial susceptibility (AOAC, 2005) [1].

2.5.2 Total Soluble Solids (TSS)

Total soluble solids (TSS) were measured using a digital refractometer, with results expressed in degrees Brix (°Brix). TSS reflects the concentration of dissolved solids, primarily sugars, and is a key indicator of jam consistency and preservation potential (Ranganna, 2004) [29].

2.5.3 pH and Titratable Acidity

The pH of the jam samples was measured using a calibrated digital pH meter. Titratable acidity was determined by titrating a known volume of jam homogenate against 0.1N NaOH, using phenolphthalein as an indicator. Results were expressed as percent citric acid equivalents. Acidity is essential for flavour development, gel formation, and microbial stability (AOAC, 2005; Ranganna, 2004) [1, 29].

2.5.4 Reducing and Total Sugars

Reducing and total sugars were quantified following the Lane and Eynon titration method, which is based on the reduction of Fehling's solution by sugars under heat. Total sugars include both reducing and non-reducing sugars and are expressed as a percentage of the sample (Ranganna, 2004; AOAC, 2005) [30, 1].

2.5.5 Mineral Content (Iron)
Iron content was estimated using Atomic Absorption Spectrophotometry (AAS) after wet digestion of the samples with a di-acid mixture (HNO_3: $HClO_4$). Iron is a vital micronutrient, and its quantification reflects the nutritional enhancement provided by jaggery and fruit components (ICMR, 2010; Ghosh and Mitra, 2021) [15, 12].

2.5.6 Viscosity
Viscosity was measured using a Brookfield digital viscometer equipped with an appropriate spindle at room temperature. Viscosity assessment is crucial for determining the flow behaviour and spreadability of jam, which directly influences consumer acceptability (Ranganna, 2004; Rao and Raju, 2004) [30, 33].

2.5.7 Colour
Colour parameters (L*, a*, b*) were determined using a Hunter Lab Colorimeter. The L* value indicates lightness, a* indicates the red/green axis, and b* the yellow/blue axis. Colour analysis is important for evaluating visual appeal and consumer perception (Pathare *et al.*, 2013) [26].

2.5.8 Microbial quality
Microbial safety was assessed by determining the Total Plate Count (TPC) using the pour plate technique on nutrient agar. Serial dilutions of the jam samples were plated and incubated at 37 °C for 24-48 hours. The microbial load was expressed as colony-forming units per gram (CFU/g), providing an indication of product safety and shelf life (FSSAI, 2020; Jay, 2000) [10, 7].

2.6 Sensory Evaluation: Sensory evaluation was performed using a 9-point hedonic scale by a panel of fifteen semi-trained members. The jam samples were assessed for colour, flavour, texture, spreadability, and overall acceptability. Colour was judged for natural appearance, flavour for balance of sweetness and fruitiness, texture for mouthfeel and consistency, and spreadability for ease of application. Overall acceptability reflected the panellists' general preference. The evaluation followed standard sensory analysis protocols as described by Lawless and Heymann (2010) [20] and Ranganna (2001) [30].

3. Results and Discussion
3.1 Physicochemical and Nutritional Analysis
The prepared hot jaggery-based fruit jams were analyzed for their key physicochemical parameters such as moisture content, TSS, pH, and acidity, which influence product quality and shelf life. In addition, nutritional attributes like ascorbic acid, total sugars, and minerals were also evaluated to assess the health benefits of the jams. The results are presented in Table 1.

Table 1: Physicochemical and nutritional properties of hot jaggery-based fruit jams

Parameter	Apple Jam	Papaya Jam	Tamarind Jam	Guava Jam
TSS (°Brix)	68.5	69.2	68.5	68.8
pH	3.4	3.7	3.1	3.6
Moisture content (%)	30.2	29.6	31.4	30.5
Reducing Sugars (%)	29.1	30.3	28.7	30.0
Total Sugars (%)	55.8	57.2	54.5	56.7
Titratable Acidity (%)	0.42	0.38	0.65	0.40
Viscosity (cP)	3450	3620	3310	3585
TPC (log cfu/g)	< 1.0	< 1.0	< 1.0	< 1.0
Water activity	0.62	0.60	0.64	0.61
L*	45.2	47.6	42.1	46.9
a*	12.3	13.2	11.8	13.0
b*	5.1	5.6	4.7	5.3
Iron (mg/100g)	1.25	2.03	1.88	1.64

3.1.1 Physicochemical Analysis
The physicochemical properties of hot jaggery-based fruit jams are summarized in Table 1 The Total Soluble Solids (TSS) content of the jams ranged from 68.5 to 69.2°Brix, with papaya jam exhibiting the highest TSS (69.2°Brix), followed by guava, apple, and tamarind jams (shown in Fig 2) These results are consistent with previous studies, such as Jaiswal *et al.* (2015) [16], they reported similar TSS values in jamun-based products. The elevated TSS in papaya jam can be attributed to its higher intrinsic sugar content and the concentration effect during thermal processing, which facilitates moisture reduction and preservation (Ranganna, 2001) [30].

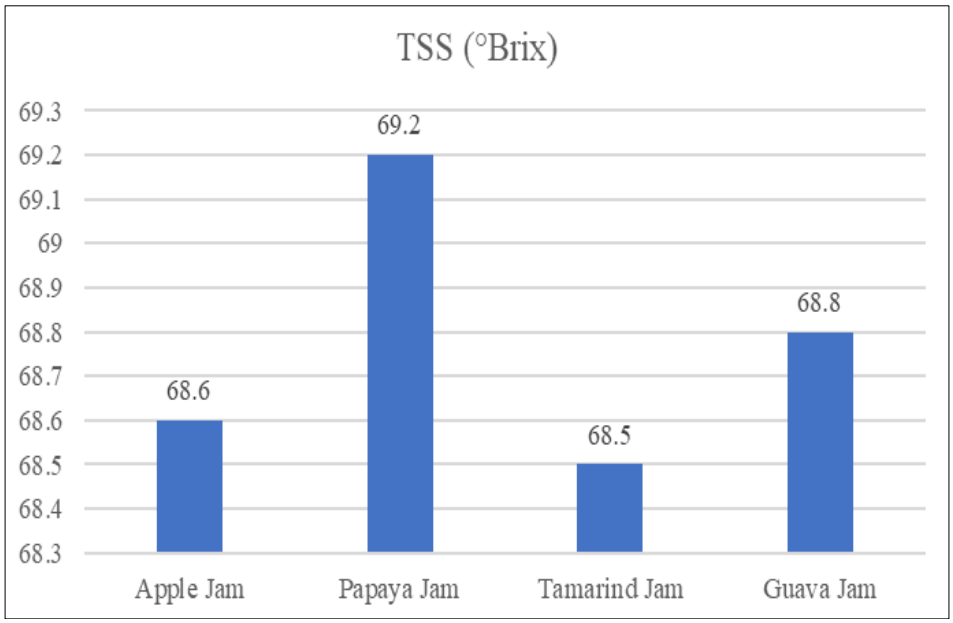

Fig 2: TSS of various fruit jam

The pH values of the jams varied between 3.1 and 3.7, with papaya jam showing the highest pH (3.7) while lowest in tamarind jam (3.1), reflecting the natural acid profiles of the respective fruits (Shown in Figure 3) These findings align with those of Shahnawaz and Sheikh (2011) [35], who reported that fruit type and organic acid composition significantly influence jam pH. Lower pH values, particularly in tamarind jam, are beneficial for microbial stability and gel formation (Ranganna, 2001) [30].

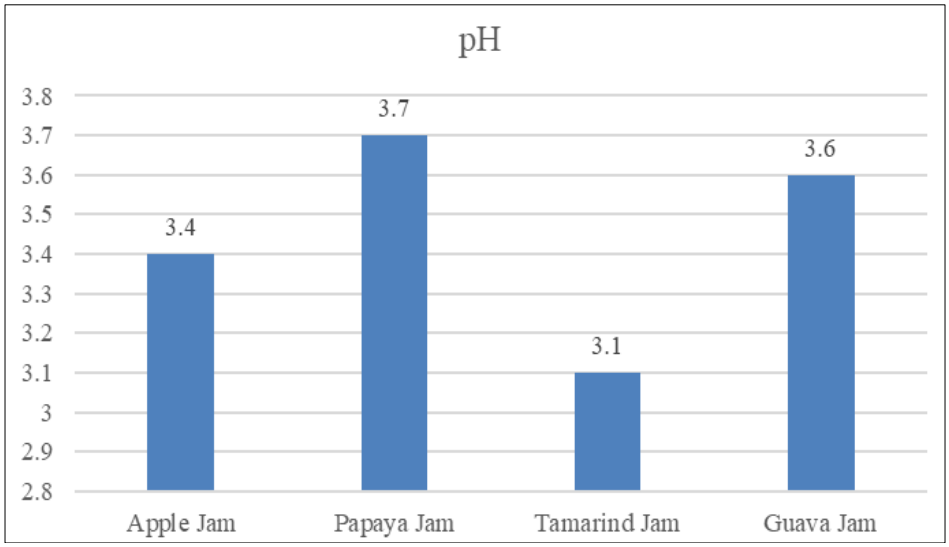

Fig 3: pH of various fruit jam

Reducing and total sugars contents were highest in papaya jam (30.3% and 57.2%, respectively), followed by guava, apple, and tamarind jams (Shown in Figure 4). The integration of hot jaggery contributed to the elevated sugar levels, enhancing sweetness, mouthfeel, and flavour perception. Higher sugar concentrations also promote increased viscosity and improved gel structure, which are critical for texture and shelf stability (Baixuli *et al.*, 2007 [3]; Korus *et al.*, 2007) [19].

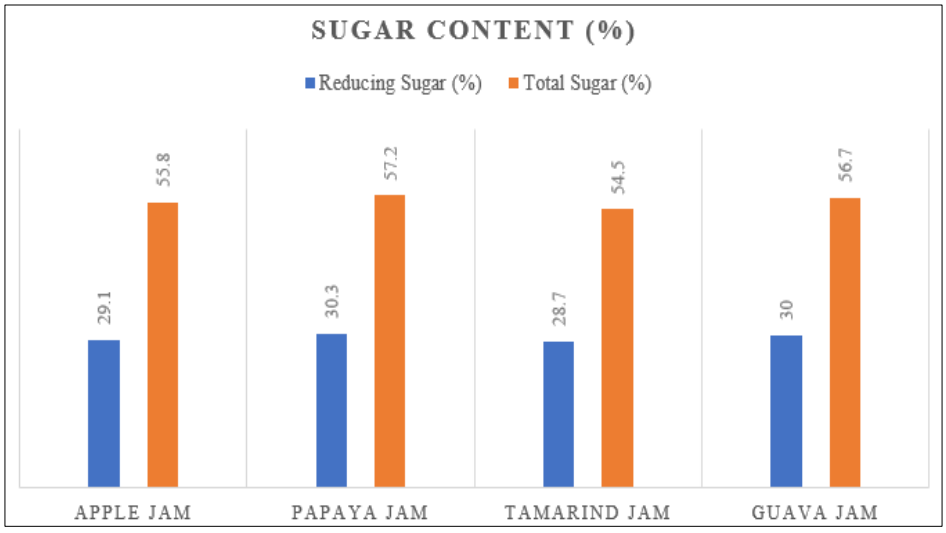

Fig 4: Sugar content in various fruit jam

Moisture content ranged from 29.6% (papaya) to 31.4% (tamarind). Rapid heating in the continuous hot jaggery process facilitated efficient moisture reduction, resulting in desirable texture and extended shelf life (Shown in Figure 4) These findings are in agreement with standard jam formulations and processing studies (AOAC, 2005; Babu *et al.*, 2014; Singh *et al.*, 2019) [1, 2, 36].

Titratable acidity ranged from 0.38% (papaya) to 0.65% (tamarind), with higher values in tamarind jam due to its natural tartaric and malic acid content (Shown in Figure 5) Acidity is essential for flavour development, pectin gelation, and microbial inhibition, and the observed values fall within the recommended range for fruit preserves (Ranganna, 2001) [30]. The viscosity of the jams ranged from 3310 to 3620 cP, with papaya jam displaying the highest viscosity, likely due to its higher pectin and sugar content (Shown in Figure 6) Increased viscosity is associated with better spread ability and gel strength. Higher viscosity in papaya jam is likely due to its naturally higher pectin and total sugar content, which enhances the formation of a stable gel matrix during heating, as supported by Korus *et al.* (2007) [19] higher soluble solids and pectin levels significantly contribute to increased viscosity and better consistency in fruit-based products.

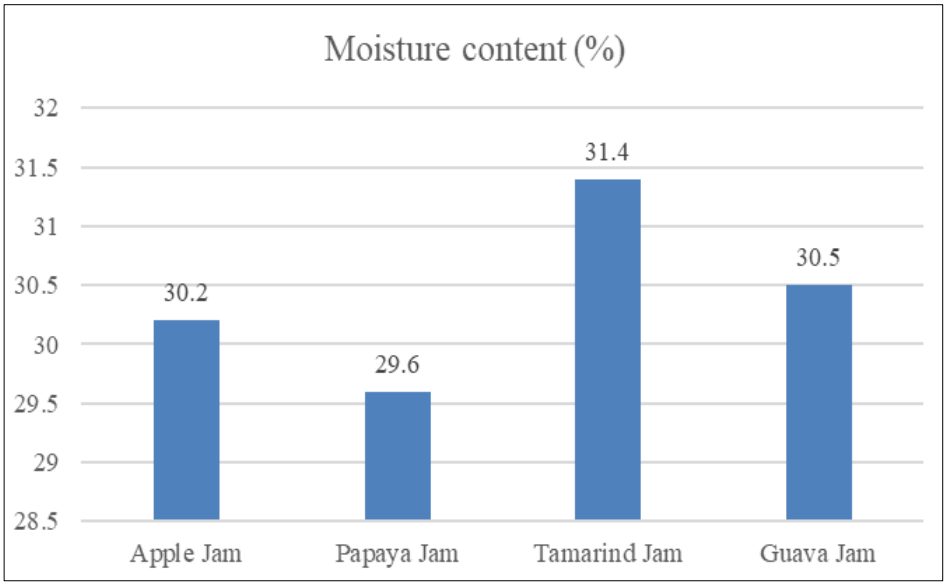

Fig 5: Moisture content of various fruit jam

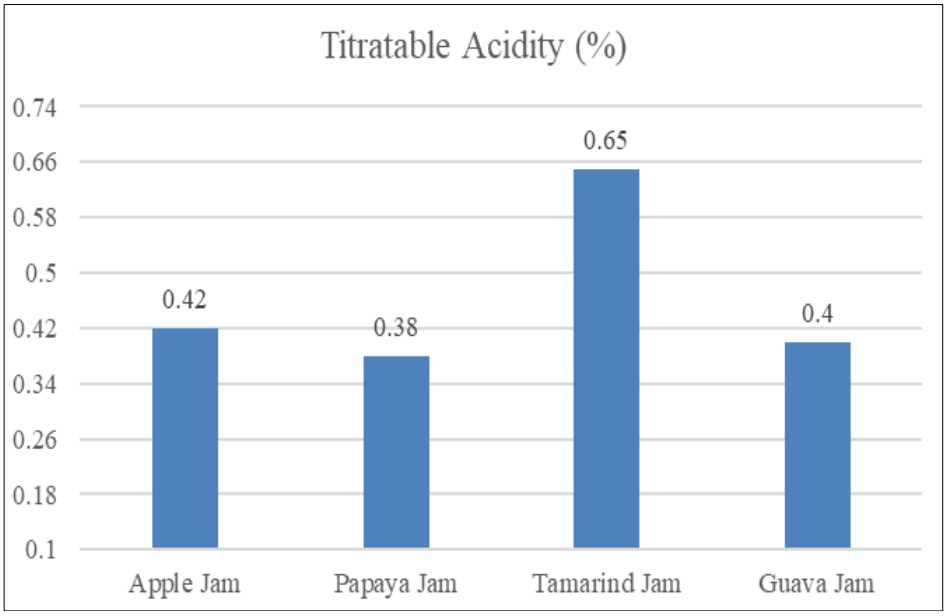

Fig 6: Titratable acidity in various fruit jam

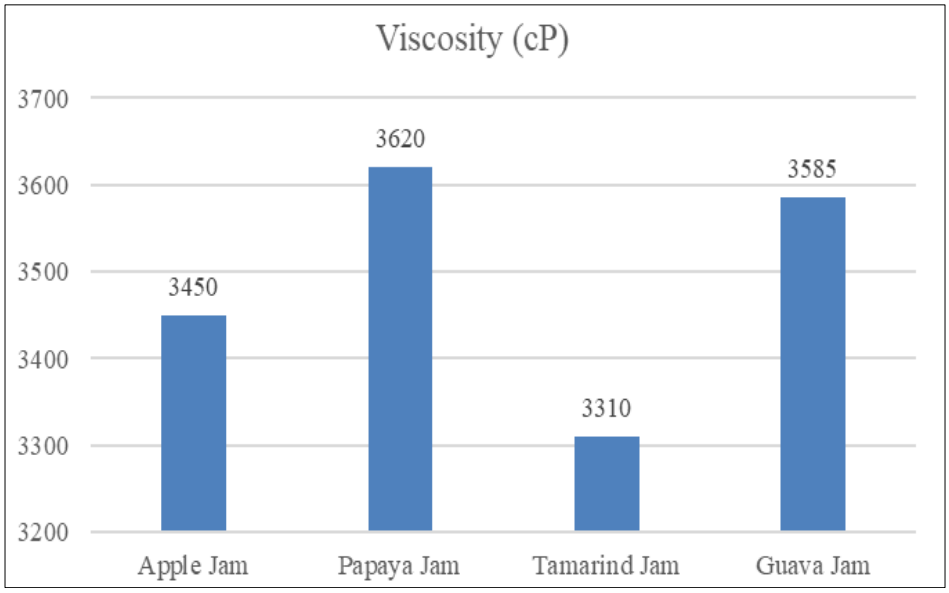

Fig 7: Viscosity of different fruit jam

All hot jaggery-based jam samples exhibited Total Plate Count (TPC) values below 1.0 log cfu/g, indicating microbial quality within range and the absence of viable spoilage or pathogenic microorganisms. According to the AOAC, (2005) [1] standards and international food safety guidelines, TPC levels below 10^2 cfu/g (i.e., < 2.0 log cfu/g) are considered microbiologically safe for fruit-based preserves. The low TPC values observed in this study can be attributed to the high sugar content, low water activity (aw 0.60-0.64), low pH, and the thermal processing conditions during jam preparation using hot jaggery. These factors act synergistically to inhibit microbial growth and ensure product safety during storage.

Water activity (aw) values ranged from 0.60 to 0.64, with papaya jam showing the lowest (0.60) (shown in Figure 8) Low aw is critical for inhibiting microbial growth and ensuring product stability (Fennema, 1996 [8]; Rahman, 2009) [27]. The observed aw values are within the safe limits for shelf-stable fruit jams and correlate with higher TSS and viscosity.

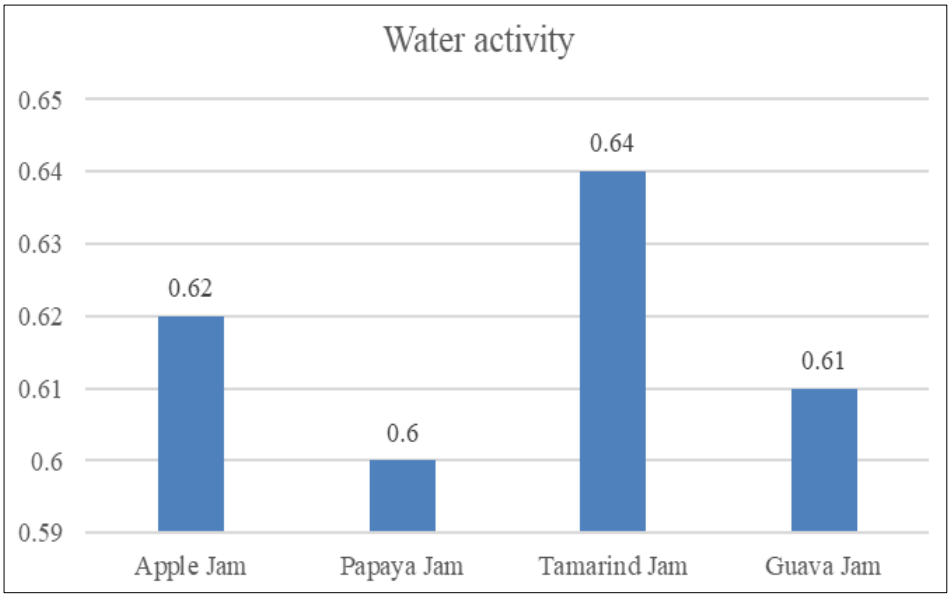

Fig 8: Water activity of different fruit jam

Iron content in the jams ranged from 1.25 to 2.03 mg/100g, with papaya jam containing the highest amount. The enhanced iron content is attributed to both the natural mineral profile of papaya and the contribution of jaggery, a known source of dietary iron (Gopalan *et al.*, 2007 [13]; Ghosh and Mitra, 2021) [12]. These results confirm the nutritional value added by incorporating jaggery into fruit jams. Colour measurements (L*, a*, b*) indicated that papaya and guava jams had higher lightness and red/yellow hues, contributing to their visual appeal. Colour is a key quality attribute influencing consumer acceptability (Pathare *et al.*, 2013) [26].

3.1.2 Sensory Evaluation

Sensory evaluation scores are presented in Table 2. Papaya jam achieved the highest overall acceptability (8.6), followed by guava, apple, and tamarind jams. Panelists rated papaya jam superior in colour, flavour, texture, and spreadability, likely due to its vibrant hue, balanced sweetness, and smooth consistency. The use of hot jaggery contributed to enhanced flavour depth and natural sweetness, in agreement with findings by Sanz *et al.* (2008) [34]. Statistical analysis (ANOVA) confirmed that differences in sensory scores were significant (p<0.05).

Table 2: Sensory evaluation of hot jaggery-based fruit jams

Jam Type	Colour	Flavour	Texture	Spreadability	Overall Acceptability
Apple jam	8.1	8.2	8.0	8.1	8.2
Papaya jam	8.4	8.5	8.3	8.5	8.6
Tamarind jam	7.8	8.0	7.9	7.8	8.0
Guava jam	8.3	8.4	8.1	8.3	8.4

3.2 Process Integration and Efficiency

The integrated hot jaggery-based jam production process demonstrated technical feasibility and energy efficiency. Compared to conventional batch processing, this method resulted in a 13.6% reduction in fuel consumption and a 21.5% decrease in labour requirements, attributable to the direct use of hot jaggery at the strike temperature (105-110 °C) (Babu *et al.*, 2014) [2]. This eliminated the need for separate heating steps, improved heat utilization, and reduced operational costs, supporting the findings of Rajkumar *et al.* (2007) [28].

3.3 Shelf-Life Study

Generally, the storage duration of most of jam is over 30 days based on its sensory and physicochemical characteristics during storage periods Microbial counts remained below detectable limits, confirming the safety and effectiveness of the thermal and sugar-based preservation method. TSS, pH, and colour remained stable during storage, corroborating the shelf-stability of high-sugar fruit products (AOAC, 2005) [1].

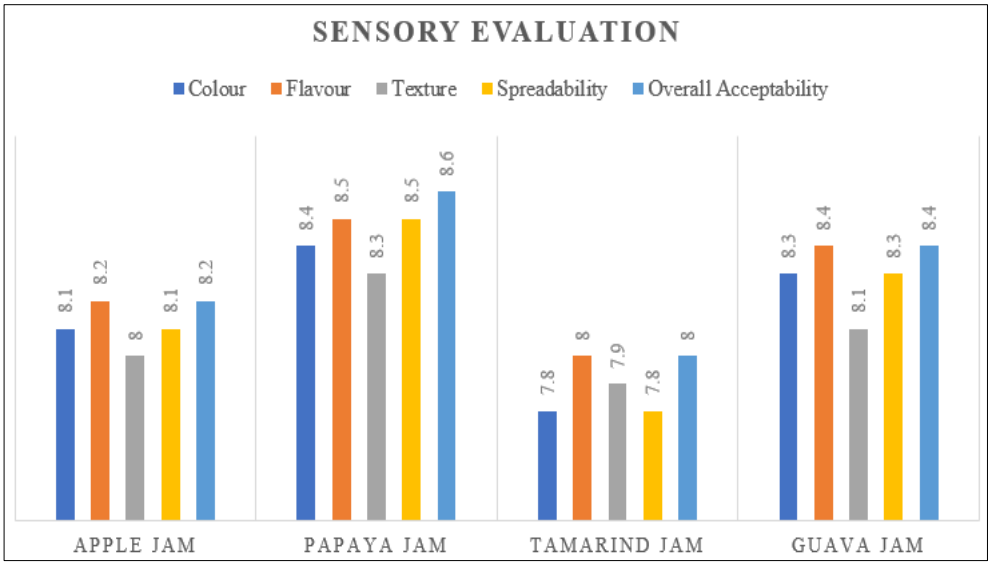

Fig 9: Sensory Evaluation of Hot Jaggery-Based Fruit Jams

4. Conclusion

This study established the feasibility of integrating hot jaggery syrup at the strike stage (105-110 °C) into jam production, which eliminated reheating and resulted in 13.6% fuel savings and 21.5% reduction in labour. Among the four fruits evaluated, papaya jam showed the most desirable properties, with highest TSS (69.2 °Brix), viscosity (3620 cP), iron content (2.03 mg/100 g), lowest water activity (0.60), and highest sensory acceptability (8.6). The process yielded nutritionally enriched, microbiologically safe, and shelf-stable jams, while demonstrating economic and environmental sustainability. These findings highlight hot jaggery as a functional alternative to refined sugar and support its commercialization for value-added fruit products, especially in rural food industries.

5. Acknowledgment

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