

Original Article : Open Access

Studies on quality evaluation of Indian mulberry (*Morinda citrifolia* L.) incorporated fruit jam

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Article Info

Article history

Received 17 November 2025

Revised 21 December 2025

Accepted 22 December 2025

Published Online 30 December 2025

Keywords

Indian mulberry (*Morinda citrifolia* L.)

Incorporated jam

Physicochemical properties

Sensory evaluation

Shelf-life

Abstract

The present investigation aimed to develop value-added incorporated jams from Indian mulberry (*Morinda citrifolia* L.) fruit and to evaluate their physicochemical, sensory and microbial quality during ambient storage. Indian mulberry juice was blended with amla, sathukkudi and orange at optimized ratios of 60:40, 70:30 and 80:20, respectively, along with a control (100% Indian mulberry). Indian mulberry fruit is a rich source of bioactive compounds such as phenolic acids (chlorogenic acid, gentisic acid and p-hydroxybenzoic acid), flavonoids, iridoids, phenylpropanoids, polysaccharides and noniosides, which exhibit antioxidant, anti-inflammatory, immunomodulatory and hepatoprotective activities. All jam formulations were packed in glass and PET containers and stored at room temperature for 90 days. The initial total soluble solids (TSS) of the jams ranged from 68.0 to 68.5°Brix and remained stable (68.0 to 68.6°Brix) throughout storage. During storage, pH increased from 3.31 to 3.49 in the control and from 4.31 to 4.52 in Indian mulberry with amla jam, while titratable acidity declined from 1.18% to 1.02%. Reducing sugars increased from 6.06 to 6.83 g/100 g, whereas total sugars slightly decreased from 58.30 to 57.36 g/100 g, indicating sucrose hydrolysis. Ascorbic acid content decreased from 18.76 to 16.21 mg/100 g in the control with higher retention observed in Indian mulberry with orange jam (20.63 to 19.08 mg/100 g). Tannin content declined from 0.716% to 0.611% tannic acid, while non-enzymatic browning increased from 0.208 to 0.259 absorbance units. Sensory evaluation revealed that Indian mulberry with orange jam recorded the highest overall acceptability scores (7.90 to 7.81). Microbial counts increased marginally but remained within permissible limits. The study demonstrates that fruit incorporation enhances sensory acceptability while retaining nutritional and bioactive functionality, supporting the potential of Indian mulberry incorporated jams as shelf-stable functional fruit preserves.

1. Introduction

In this study, worked with Indian mulberry (*Morinda citrifolia* L.) a fruit characterized by a light, earthy scent reminiscent of damp leaves after rain. Indian mulberry grows in the Andaman and Nicobar Islands, where it is traditionally cultivated by local communities under humid coastal conditions. Historically, Indian mulberry fruits have been used for both dietary and medicinal purposes, including chewing the fruit to relieve sore throats. Across mainland India, the plant is commonly distributed along the coastal regions of Kerala, Karnataka, Tamil Nadu, and other shoreline areas. In traditional Indian Ayurveda, noni is referred to as 'Ayushka' meaning longevity. The plant is known by several regional names, including Baratundi in Maharashtra, Manjanathi in Tamil Nadu, and Bandamaddi in Andhra Pradesh.

Indian mulberry produces clusters of fruits that emit a pungent odor upon ripening, which has led to its common names 'cheese fruit'. Despite its strong odor and bitter taste, the fruit has historically been consumed during periods of food scarcity. Indian mulberry commonly called noni bears pale green fruits with a sharp, earthy odor and is widely used as an ingredient in nutraceuticals and functional foods ranging from energy bars to fermented health beverages. The plant is a small evergreen tree that thrives in bright coastal plains and extends into forested hillsides at elevations of up to approximately 1,300 feet above sea level. It is often found growing along old lava flows, where its roots firmly anchor into rough, black rock. Botanically, the plant can be identified by its straight trunk, broad glossy elliptic leaves, clusters of white tubular flowers and distinctive yellow fruits resembling small grenades. The fruits can grow to approximately 12 cm or more in diameter with a coarse surface divided into uneven polygonal sections. The seeds are small, triangular and reddish-brown each possessing an air sac that facilitates flotation and dispersal across coastal regions. When fully ripe, Indian mulberry emits a strong odor and exhibits an intensely sour taste often compared to overripe cheese.

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The characteristic odor of Indian mulberry fruit is attributed to volatile compounds such as octanoic acid, hexanoic acid, and 3-methyl-3-buten-1-ol (Wang *et al.*, 2021). Phytochemical analysis of *Indian mulberry* fruit revealed the presence of a wide range of amino acids. Eighteen amino acids were identified including alanine, arginine, aspartic acid, cysteine, glutamic acid, glycine, histidine, isoleucine, leucine, lysine, methionine, phenylalanine, proline, serine, threonine, tryptophan, tyrosine and valine. These compounds were detected exclusively within the fruit matrix. Molecular formula analysis confirmed that the identified compounds comprised both essential and non-essential amino acids. The presence of essential amino acids such as lysine, methionine, phenylalanine, tryptophan, leucine, isoleucine and valine highlights the nutritional significance of Indian mulberry fruits. These findings suggest that Indian mulberry fruit has potential as a nutrient rich ingredient for functional foods and nutraceutical applications (West *et al.*, 2011).

Further phytochemical investigations of Indian mulberry fruit revealed the presence of various bioactive compounds including phenolic acids, phenylpropanoids and saccharides. The phenolic acid fraction contained chlorogenic acid, gentisic acid and *p*-hydroxybenzoic acid, which are well known for their antioxidant properties (Inada *et al.*, 2017). Phenylpropanoid compounds such as butyl 3-(2,4-dihydroxy-5-methoxyphenyl) propionate and methyl 3-(2,4-dihydroxy-5-methoxyphenyl) propionate were also identified confirming the presence of phenolic ester derivatives in the fruit matrix (Wang *et al.*, 2011). The saccharide profile included D-glucose, methyl β -D-fructofuranoside, methyl α -D-fructofuranoside, nonioside A and nonioside B predominantly localized in the fruit pulp (Almeida *et al.*, 2019; Su *et al.*, 2005). These findings demonstrate the chemical complexity and functional relevance of Indian mulberry fruit.

Additional studies have reported a broad spectrum of sugars, sterols, vitamins and other low-molecular-weight compounds distributed across different plant parts. The saccharide fraction included noniosides C-H, all identified in the fruits indicating structural diversity among glycosidic compounds. Sterol analysis revealed the presence of β -sitosterol-3-O- β -D-glucopyranoside in fruits and stigmasterol in leaves confirming the occurrence of bioactive) phyosterols (Su *et al.*, 2005; Saludes *et al.*, 2002). The vitamin profile of Indian mulberry fruits included vitamins C, B1-B12, E and K underscoring their nutritional richness (Almeida *et al.*, 2019). Several additional compounds including 2,6-di-O-(β -D-glucopyranosyl)-1-O-octanoyl-1- β -D-glucopyranose, flower-derived glycosides, morinaphthalene, morinaphthalenone, morindafurone, morinthone and β -D-glucopyranose penta-acetate were predominantly detected in the fruit (Singh *et al.*, 2020; Siddiqui *et al.*, 2008).

Antioxidant evaluations of Indian mulberry fruit have demonstrated strong free-radical scavenging and oxidative stress-reducing activities in both *in vitro* and *in vivo* studies. Standard antioxidant assays including DPPH, ABTS, hydroxyl and superoxide radical scavenging, lipid peroxidation inhibition and total antioxidant capacity showed concentration dependent antioxidant activity for fruit polysaccharides, polysaccharide-type polyphenols, ethanol extracts and fermented Indian mulberry juice. *In vivo* studies using C57BL/6 mice, Kunming mice and Sprague Dawley rats subjected to high-fat diets or oxidative stress revealed that supplementation with fruit phenolic extracts, fruit wine water extracts or fruit polysaccharides significantly reduced hepatic reactive oxygen species and malondialdehyde

levels, while enhancing antioxidant enzyme activities such as glutathione and catalase (Zhang *et al.*, 2020; Yang, X *et al.*, 2020; Yang, X *et al.*, 2020; Wang *et al.*, 2022). Fermented Indian mulberry juice activated the Nrf2/ARE signaling pathway enhancing antioxidant gene expression and restoring redox balance. Fruit polysaccharides also modulated gut microbiota composition increased short-chain fatty acid production and improved intestinal barrier function collectively reducing hepatic oxidative stress and inflammation (Yang *et al.*, 2020).

Despite its high nutritional and therapeutic potential the intense flavor of Indian mulberry fruit poses challenges for product development. Consequently, blending Indian mulberry pulp or jam with other fruit matrices is considered an effective strategy to improve sensory acceptability while retaining nutritional value. In the present study, squash was prepared by blending Indian mulberry jam with other fruit jams to reduce its harsh flavor and the nutritional quality of the resulting beverage was evaluated.

2. Materials and Methods

2.1 Plant material authentication

The plant material Indian mulberry (*Morinda citrifolia* L.) was botanically authenticated by comparison with a reference herbarium specimen and expert taxonomic assessment. A voucher specimen representing a fruiting individual collected from Chidiatappu is deposited at the Indian Institute of Integrative Medicine (IIIM) Herbarium, Jammu under Accession Number-16668 and it was identified by B. K. Kapahi. Morphological traits, including leaf architecture and floral characteristics were used to confirm species identity. Fully mature Indian mulberry fruits were obtained from the Horticultural College and Research Institute, Periyakulam, Tamil Nadu, India and transported to the laboratory in cushioned containers.

2.2 Extraction of Indian mulberry juice

The extraction of Indian mulberry juice was commercially produced by the natural fermentation process using drip extraction method (traditional method) as described (Dittmar, 1993) the ripened fruit was packed into a food grade air tight container for the period of 4 to 8 weeks. The juice seeps out of the fruit was decanted from the container after 8 weeks, filtered and bottled. This ageing process is impelling but time consuming and the colour of the juice was black in colour. The fruit was often subjected to intense light and temperature in the tropics, resulting in the breakdown of phytochemicals and nutrient.

2.3 Physicochemical analysis

The proximate composition of Indian mulberry jam was analyzed for various parameters. Total soluble solids (TSS) were measured using a hand refractometer with a range of 0 to 45°Brix. Total acidity was determined following the method described by McDonald (1960) and pH was measured according to the procedure described by Hart (1971). Reducing sugars and total sugars were quantified using the Shaffer-Somogyi micro method. The ascorbic acid content was determined using the 2,6-dichlorophenol indophenol titration method. Tannin content was estimated spectrophotometrically at 700 nm using a UV-visible spectrophotometer (Systronics, India) following the standard procedure described by Hart (1971). Non-enzymatic browning was assessed spectrophotometrically at 440 nm according to the method outlined by Ranganna (1995).

2.4 Sensory evaluation

The developed Indian mulberry fruit jam was evaluated for sensory attributes including color, appearance, flavor, texture, taste and overall acceptability using a nine-point Hedonic rating scale (1-dislike extremely, 9-like extremely) as described by Amerine *et al.* (1965).

2.5 Processing of Indian mulberry fruit incorporated jam

The Indian mulberry fruit incorporated jam was prepared by using the fruits of amla, sathukkudi and orange. The optimum proportion of the fruits in preparing incorporated jam to suit the consumers

were found as Indian mulberry with amala (60:40), Indian mulberry with sathukkudi (70:30) and Indian mulberry with orange (80:20). Each incorporated jam and the control sample (100% Indian mulberry) was prepared in large scale and packed individually in two types of containers such as and glass bottle (P_1) PET bottle (P_2). All prepared incorporated jams along with the control were stored at room temperature for a period of 90 days. The samples were analyzed at 30 day intervals to assess changes in physicochemical composition, microbial load and sensory attributes including taste and aroma (Figure 1).



Figure 1: Preparation of jam from Indian mulberry fruit incorporated with other fruit.

2.6 Statistical analysis

Data from all experiments were analyzed to evaluate the effects of storage conditions and storage duration on the measured parameters. The study employed a factorial completely randomized design (FCRD) was statistically analyzed using AGRESS software.

3. Results

3.1 Chemical changes of the Indian mulberry fruit incorporated jam

Indian mulberry fruit jam was prepared and stored in different containers. Samples were analyzed at 30 day intervals over a 90 day period to monitor changes in pH, total acidity, total and reducing

sugars, total soluble solids (TSS), ascorbic acid, tannin content and non-enzymatic browning. The results were recorded systematically in tabular form to assess physicochemical changes during storage.

3.2 pH

Table 1 presents the changes in pH of Indian mulberry fruit jam stored in packaging types P_1 and P_2 at room temperature. The pH of all samples increased slightly over the storage period. In P_2 , the pH values for samples Indian mulberry, Indian mulberry with amla, Indian mulberry with sathukkudi and Indian mulberry with orange were 3.49, 4.43, 3.52 and 3.58, respectively. The data also indicated differences in texture between packaging types and storage intervals with some batches showing increased consistency during storage.

Table 1: Changes in pH contents of jam from Indian mulberry incorporated with other fruits

Storage period (days)	(P_1)				(P_2)			
	C_0P_1	C_1P_1	C_2P_1	C_3P_1	C_0P_2	C_1P_2	C_2P_2	C_3P_2
0	3.31 ± 0.09	4.31 ± 0.01	3.32 ± 0.09	3.42 ± 0.03	3.31 ± 0.06	4.31 ± 0.02	3.32 ± 0.005	3.42 ± 0.01
30	3.36 ± 0.02	4.38 ± 0.05	3.40 ± 0.04	3.49 ± 0.11	3.31 ± 0.04	4.33 ± 0.10	3.29 ± 0.09	3.49 ± 0.07
60	3.48 ± 0.08	4.43 ± 0.09	3.47 ± 0.04	3.53 ± 0.009	3.36 ± 0.03	4.38 ± 0.09	3.36 ± 0.09	3.51 ± 0.004
90	3.49 ± 0.04	4.52 ± 0.14	3.58 ± 0.11	3.72 ± 0.11	3.43 ± 0.07	4.43 ± 0.10	3.45 ± 0.01	3.54 ± 0.08
SE(d)	0.307459	1.126039	0.44452	0.639228	0.127850	0.132708	0.091279	0.922960
CD (0.05)	0.576*	0.953**	0.892**	0.613**	0.946**	0.341	0.613**	0.405

Note: Glass container- P_1 ; Pet bottle- P_2 ; C_0P_1 -Indian mulberry control; C_1P_1 -Indian mulberry with amla; C_2P_1 -Indian mulberry with sathukkudi; C_3P_1 -Indian mulberry with orange; C_0P_2 -Indian mulberry control; C_1P_2 -Indian mulberry with amla; C_2P_2 -Indian mulberry with sathukkudi; C_3P_2 -Indian mulberry with orange.

3.3 Acidity

As storage progressed, the acidity of all jam samples decreased in both packaging types (Table 2 and Figure 2). The Indian mulberry jam showed a gradual reduction in total acidity, declining from 1.18% to 1.04% in glass bottles (P_1) and to 1.02% in PET bottles (P_2) by the end of the 90-day storage period at room temperature. Similarly, the total acidity of other samples decreased steadily over the same period with recorded ranges of 1.42 to 1.29% (Indian mulberry with

amla), 1.39 to 1.28% (Indian mulberry with sathukkudi) and 1.64 to 1.21% (Indian mulberry with orange) in P_1 and 1.18 to 1.04% (Indian mulberry with amla), 1.42 to 1.29% (Indian mulberry with sathukkudi) and 1.39 to 1.24% (Indian mulberry with orange) in P_2 . Statistical analysis indicated significant differences in acidity among samples, packaging types and storage intervals with jams stored in glass bottles retaining higher acidity for a longer period (Potterat and Hamburger, 2017).

Table 2: Changes in acidity (%) of jam from Indian mulberry incorporated with other fruits

Storage period (days)	(P_1)				(P_2)			
	C_0P_1	C_1P_1	C_2P_1	C_3P_1	C_0P_2	C_1P_2	C_2P_2	C_3P_2
0	1.18 ± 0.01	1.42 ± 0.02	1.39 ± 0.04	1.64 ± 0.03	1.18 ± 0.007	1.42 ± 0.01	1.39 ± 0.01	1.64 ± 0.02
30	1.12 ± 0.01	1.38 ± 0.01	1.35 ± 0.02	1.58 ± 0.02	1.15 ± 0.01	1.40 ± 0.02	1.34 ± 0.02	1.57 ± 0.001
60	1.03 ± 0.02	1.32 ± 0.03	1.32 ± 0.01	1.33 ± 0.03	1.08 ± 0.03	1.38 ± 0.03	1.26 ± 0.01	1.50 ± 0.003
90	1.02 ± 0.01	1.29 ± 0.001	1.28 ± 0.008	1.21 ± 0.03	1.04 ± 0.02	1.29 ± 0.01	1.24 ± 0.01	1.48 ± 0.003
SE(d)	0.07387	0.06112	0.05695	0.18655	0.06476	0.05541	0.07218	0.12439
CD (0.05)	0.650*	0.603*	0.865**	0.894**	0.693*	0.691*	0.716**	0.805*

Note: Glass container- P_1 ; Pet bottle- P_2 ; C_0P_1 -Indian mulberry control; C_1P_1 -Indian mulberry with amla; C_2P_1 -Indian mulberry with sathukkudi; C_3P_1 -Indian mulberry with orange; C_0P_2 -Indian mulberry control; C_1P_2 -Indian mulberry with amla; C_2P_2 -Indian mulberry with sathukkudi; C_3P_2 -Indian mulberry with orange.

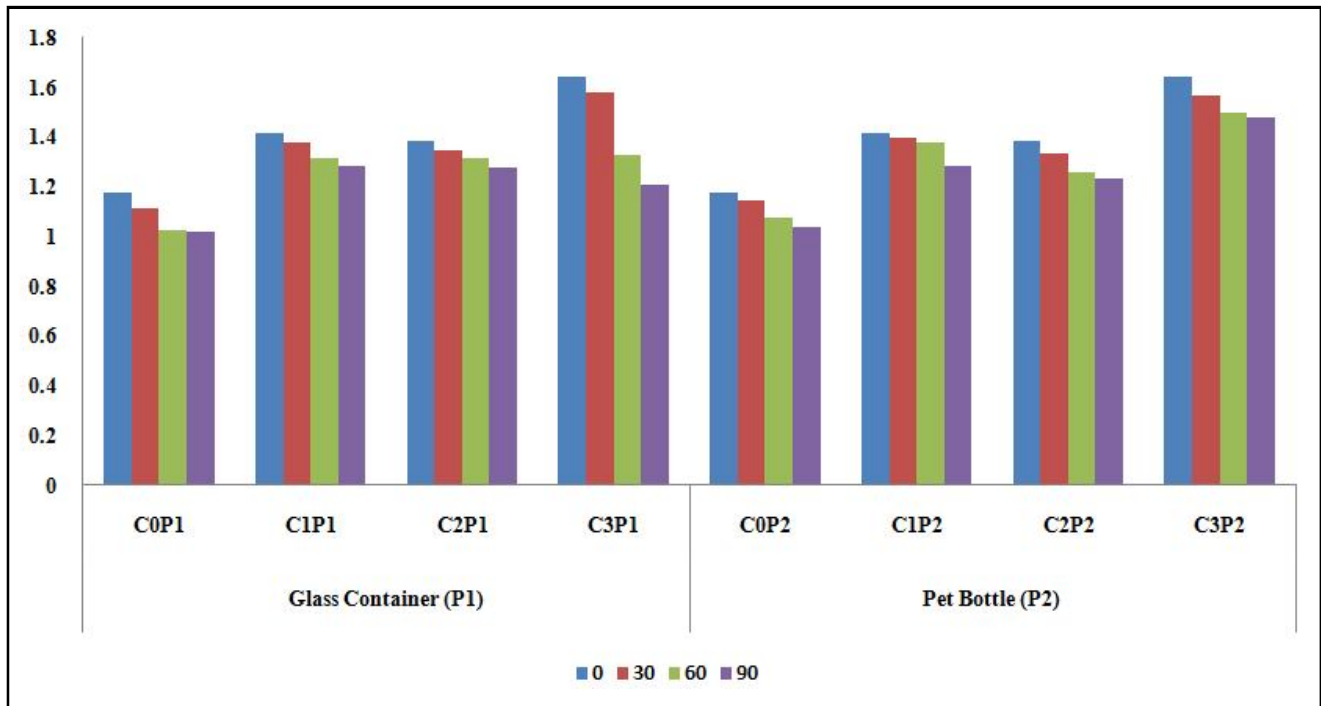


Figure 2: Acidity of jam from Indian mulberry fruit blended with other fruits.

3.4 Total soluble solids (TSS)

The total soluble solids (TSS) of the stored Indian mulberry jam remained relatively stable throughout the 90 day storage period, showing minimal variation with container type or storage time (Table 3). At initial day, the TSS values were 68.00, 68.10, 68.00 and 68.50°Brix for samples Indian mulberry, Indian mulberry with amla,

Indian mulberry with sathukkudi and Indian mulberry with orange, respectively. By the end of storage, TSS values in glass containers (P_1) were 68.20, 68.30, 68.20 and 68.60° Brix, while PET bottles (P_2) showed 68.00, 68.10, 68.00 and 68.50° Brix, respectively. Statistical analysis indicated no significant changes in TSS among samples, packaging types or storage intervals suggesting that the soluble solids content was largely unaffected by storage conditions.

Table 3: Changes in TSS (°brix) content of jam from Indian mulberry incorporated with other fruits

Storage period (days)	(P_1)				(P_2)			
	C_0P_1	C_1P_1	C_2P_1	C_3P_1	C_0P_2	C_1P_2	C_2P_2	C_3P_2
0	68.0 ± 0.60	68.1 ± 2.27	68.0 ± 1.11	68.5 ± 1.13	68.0 ± 1.52	68.1 ± 1.48	68.0 ± 0.08	68.5 ± 2.05
30	68.0 ± 1.89	68.1 ± 2.13	68.1 ± 0.23	68.5 ± 1.95	68.0 ± 1.48	68.1 ± 2.17	68.1 ± 0.09	68.5 ± 2.09
60	68.2 ± 2.04	68.2 ± 1.62	68.2 ± 1.29	68.6 ± 2.10	68.1 ± 0.68	68.2 ± 0.09	68.2 ± 1.02	68.5 ± 1.67
90	68.2 ± 1.57	68.3 ± 0.46	68.3 ± 1.02	68.6 ± 1.40	68.2 ± 2.04	68.3 ± 1.53	68.2 ± 1.94	68.5 ± 0.32
SE(d)	1.769395	1.52777	1.469256	0.75964	1.56407	2.017783	0.98416	1.528489
CD (0.05)	0.035	0.356	0.226	0.236	0.129	0.115	0.356	0.873

Note: Glass container- P_1 ; Pet bottle- P_2 ; C_0P_1 -Indian mulberry control; C_1P_1 -Indian mulberry with amla; C_2P_1 -Indian mulberry with sathukkudi; C_3P_1 -Indian mulberry with orange; C_0P_2 -Indian mulberry control; C_1P_2 -Indian mulberry with amla; C_2P_2 -Indian mulberry with sathukkudi; C_3P_2 -Indian mulberry with orange.

3.5 Reducing sugar and total Sugar

During storage, total sugars in the Indian mulberry jam appeared to partially hydrolyze into simpler sugars, leading to an increase in reducing sugar content. The type of fruit blended with Indian mulberry also influenced reducing sugar levels over 90 days of storage in both glass container (P_1) and PET bottle (P_2) containers. At room temperature the initial reducing sugar content was 6.06, 8.15, 7.12 and 8.00 g 100 g for Indian mulberry, Indian mulberry with amla, Indian mulberry with sathukkudi and Indian mulberry with orange,

respectively. Total sugar content varied depending on the fruit combination with initial values of 58.30%, 38.20%, 57.94%, and 58.34% for Indian mulberry, Indian mulberry with amla, Indian mulberry with sathukkudi and Indian mulberry with orange, respectively (Tables 4 and 5). By the end of storage, total sugar content increased in all samples, reflecting partial conversion of complex sugars to reducing sugars and the changes were influenced by both the type of incorporated fruit and the packaging material (Mathivanan *et al.*, 2019).

Table 4: Changes in reducing sugar (g/100 g) content of jam from Indian mulberry incorporated with other fruits

Storage period (days)	(P ₁)				(P ₂)			
	C ₀ P ₁	C ₁ P ₁	C ₂ P ₁	C ₃ P ₁	C ₀ P ₂	C ₁ P ₂	C ₂ P ₂	C ₃ P ₂
0	6.06 ± 0.15	8.15 ± 0.11	7.12 ± 0.12	8.00 ± 0.13	6.06 ± 0.06	8.15 ± 0.21	7.12 ± 0.02	8.00 ± 0.08
30	6.67 ± 0.19	8.52 ± 0.09	7.19 ± 7.19	8.23 ± 0.21	6.34 ± 0.04	8.24 ± 0.26	7.20 ± 0.02	8.04 ± 0.08
60	6.73 ± 0.10	8.63 ± 0.09	7.70 ± 7.7	8.36 ± 0.01	6.44 ± 0.11	8.31 ± 0.02	7.24 ± 0.08	8.08 ± 0.21
90	6.83 ± 0.06	8.71 ± 0.15	7.81 ± 7.81	8.49 ± 0.23	6.53 ± 0.05	8.37 ± 0.005	7.32 ± 0.17	8.26 ± 0.005
SE(d)	0.335874	0.945134	0.499477	0.26636	0.937949	0.299187	0.26206	0.33957
CD (0.05)	0.610*	0.827**	0.515*	0.724**	0.531*	0.444	0.707**	0.345*

Note: Glass container-P₁; Pet bottle-P₂; C₀P₁-Indian mulberry control; C₁P₁-Indian mulberry with amla; C₂P₁-Indian mulberry with sathukkudi; C₃P₁-Indian mulberry with orange; C₀P₂-Indian mulberry control; C₁P₂-Indian mulberry with amla; C₂P₂-Indian mulberry with sathukkudi; C₃P₂-Indian mulberry with orange.

Table 5: Changes in total sugar (g/100 g) content of jam from Indian mulberry incorporated with other fruits

Storage period (days)	(P ₁)				(P ₂)			
	C ₀ P ₁	C ₁ P ₁	C ₂ P ₁	C ₃ P ₁	C ₀ P ₂	C ₁ P ₂	C ₂ P ₂	C ₃ P ₂
0	58.30 ± 1.44	58.20 ± 0.03	57.94 ± 1.93	58.34 ± 0.39	58.30 ± 1.16	58.20 ± 1.74	57.94 ± 0.94	58.34 ± 0.39
30	57.90 ± 0.82	58.10 ± 1.160	57.82 ± 1.33	58.29 ± 1.38	58.20 ± 0.99	58.02 ± 1.18	57.86 ± 0.59	58.30 ± 0.27
60	57.50 ± 1.76	58.09 ± 1.46	57.43 ± 0.93	58.02 ± 1.14	57.79 ± 0.78	57.90 ± 1.14	57.83 ± 1.06	58.14 ± 0.55
90	57.36 ± 1.60	57.63 ± 0.82	57.10 ± 1.78	57.53 ± 0.35	57.56 ± 1.40	57.86 ± 0.19	57.62 ± 1.45	58.00 ± 0.31
SE(d)	1.858813	1.086052	1.734876	1.251458	1.70712	0.88877	1.63784	1.637453
CD (0.05)	0.246	0.266	0.348	0.246	0.375	0.411	0.564*	0.285

Note: Glass container-P₁; Pet bottle-P₂; C₀P₁-Indian mulberry control; C₁P₁-Indian mulberry with amla; C₂P₁-Indian mulberry with sathukkudi; C₃P₁-Indian mulberry with orange; C₀P₂-Indian mulberry control; C₁P₂-Indian mulberry with amla; C₂P₂-Indian mulberry with sathukkudi; C₃P₂-Indian mulberry with orange.

3.6 Ascorbic acid (vitamin C)

Table 6 presents the changes in ascorbic acid (vitamin C) content of Indian mulberry jam and the control during the 90 day storage period. Both storage duration, container type and the fruit used for blending significantly affected the vitamin C content. Samples stored at room temperature in PET bottles (P₂) retained higher levels of ascorbic

acid compared to glass containers (P₁). Among the blended jams, Indian mulberry with amla and mulberry with sathukkudi exhibited higher initial and retained vitamin C levels than the batch blended with orange. Statistical analysis indicated a significant decline in ascorbic acid over time with variations observed between samples, packaging types and storage periods.

Table 6: Changes in vitamin C (mg/100 g) content of jam from Indian mulberry incorporated with other fruits

Storage period (days)	(P ₁)				(P ₂)			
	C ₀ P ₁	C ₁ P ₁	C ₂ P ₁	C ₃ P ₁	C ₀ P ₂	C ₁ P ₂	C ₂ P ₂	C ₃ P ₂
0	18.76 ± 0.37	19.06 ± 0.11	17.85 ± 0.52	20.63 ± 0.59	18.76 ± 0.53	19.06 ± 0.25	17.85 ± 0.52	20.63 ± 0.59
30	17.33 ± 0.40	18.85 ± 0.07	17.44 ± 0.35	20.11 ± 0.61	17.34 ± 0.12	18.88 ± 0.37	17.43 ± 0.34	20.22 ± 0.54
60	16.67 ± 0.46	18.48 ± 0.06	17.01 ± 0.23	19.43 ± 0.23	17.06 ± 0.47	18.34 ± 0.38	17.02 ± 0.23	19.64 ± 0.42
90	16.21 ± 0.18	17.89 ± 0.19	16.63 ± 0.02	19.08 ± 0.44	16.88 ± 0.18	17.96 ± 0.40	16.64 ± 0.03	19.44 ± 0.41
SE(d)	4.548282	4.616734	3.929719	4.456384	4.442603	3.530072	2.900420	3.343555
CD (0.05)	0.958**	0.727**	0.993*	0.985**	0.742**	0.981**	0.978**	0.966**

Note: Glass container-P₁; Pet bottle-P₂; C₀P₁-Indian mulberry control; C₁P₁-Indian mulberry with amla; C₂P₁-Indian mulberry with sathukkudi; C₃P₁-Indian mulberry with orange; C₀P₂-Indian mulberry control; C₁P₂-Indian mulberry with amla; C₂P₂-Indian mulberry with sathukkudi; C₃P₂-Indian mulberry with orange.

3.7 Tannin

A decreasing trend in tannin content was observed in all Indian mulberry jam samples during the 90 day storage period (Table 7).

Among the formulations, Indian mulberry incorporated with amla jam (Indian mulberry) consistently exhibited higher tannin content compared to Indian mulberry, Indian mulberry with sathukkudi and Indian mulberry with orange throughout the study. The initial tannin

content ranged from 0.715% to 0.830% tannic acid for Indian mulberry, Indian mulberry with amla, Indian mulberry with sathukkudi and Indian mulberry with orange. At the end of storage in glass bottles (P_1), tannin content decreased to 0.611%, 0.723%, 0.627% and 0.617% for Indian mulberry, Indian mulberry with amla,

Indian mulberry with sathukkudi and Indian mulberry with orange, respectively. Corresponding values in PET bottles (P_2) stored at room temperature were 0.628%, 0.765%, 0.645% and 0.641% tannic acid. Statistical analysis indicated significant differences in tannin content among the jam samples storage periods and packaging types.

Table 7: Changes in tannin (% tannic acid) content of jam from Indian mulberry incorporated with other fruits

Storage period (days)	(P_1)				(P_2)			
	C_0P_1	C_1P_1	C_2P_1	C_3P_1	C_0P_2	C_1P_2	C_2P_2	C_3P_2
0	0.716 ± 0.01	0.834 ± 0.008	0.734 ± 0.02	0.715 ± 0.01	0.716 ± 0.01	0.830 ± 0.03	0.734 ± 0.01	0.715 ± 0.01
30	0.687 ± 0.01	0.773 ± 0.02	0.711 ± 0.006	0.688 ± 0.012	0.695 ± 0.023	8.02 ± 0.03	0.714 ± 0.01	0.692 ± 0.01
60	0.632 ± 0.001	0.753 ± 0.01	0.659 ± 0.01	0.646 ± 0.013	0.643 ± 0.01	0.783 ± 0.02	0.685 ± 0.001	0.634 ± 0.012
90	0.611 ± 0.003	0.723 ± 0.008	0.627 ± 0.01	0.617 ± 0.11	0.628 ± 0.02	0.765 ± 0.01	0.645 ± 0.001	0.641 ± 0.13
SE(d)	0.04224	0.04882	0.04458	0.04715	0.04658	0.04379	0.04666	0.04195
CD (0.05)	1.000	0.720**	0.888**	0.947**	0.926**	0.800**	0.953**	0.931**

Note: Glass container- P_1 ; Pet bottle- P_2 ; C_0P_1 -Indian mulberry control; C_1P_1 -Indian mulberry with amla; C_2P_1 -Indian mulberry with sathukkudi; C_3P_1 -Indian mulberry with orange; C_0P_2 -Indian mulberry control; C_1P_2 -Indian mulberry with amla; C_2P_2 -Indian mulberry with sathukkudi; C_3P_2 -Indian mulberry with orange.

Table 8: Changes in non enzymatic browning (absorbance) of jam from Indian mulberry incorporated with other fruits

Storage period (days)	(P_1)				(P_2)			
	C_0P_1	C_1P_1	C_2P_1	C_3P_1	C_0P_2	C_1P_2	C_2P_2	C_3P_2
0	0.208 ± 0.002	0.221 ± 0.006	0.232 ± 0.001	0.265 ± 0.007	0.208 ± 0.006	0.221 ± 0.006	0.232 ± 0.002	0.265 ± 0.003
30	0.223 ± 0.005	0.236 ± 0.002	0.244 ± 0.006	0.281 ± 0.004	0.221 ± 0.005	0.232 ± 0.001	0.246 ± 0.002	0.272 ± 0.007
60	0.248 ± 0.001	0.242 ± 0.002	0.261 ± 0.004	0.295 ± 0.002	0.243 ± 0.005	0.241 ± 0.003	0.258 ± 0.003	0.284 ± 0.004
90	0.259 ± 0.008	0.257 ± 0.005	0.271 ± 0.008	0.317 ± 0.001	0.251 ± 0.005	0.252 ± 0.001	0.267 ± 0.008	0.312 ± 0.005
SE(d)	0.01879	0.01321	0.01495	0.01979	0.02133	0.01525	0.01757	0.02047
CD (0.05)	0.915**	0.917**	0.860**	0.921**	0.836**	0.844**	0.921**	0.816

Note: Glass container- P_1 ; Pet bottle- P_2 ; C_0P_1 -Indian mulberry control; C_1P_1 -Indian mulberry with amla; C_2P_1 -Indian mulberry with sathukkudi; C_3P_1 -Indian mulberry with orange; C_0P_2 -Indian mulberry control; C_1P_2 -Indian mulberry with amla; C_2P_2 -Indian mulberry with sathukkudi; C_3P_2 -Indian mulberry with orange.

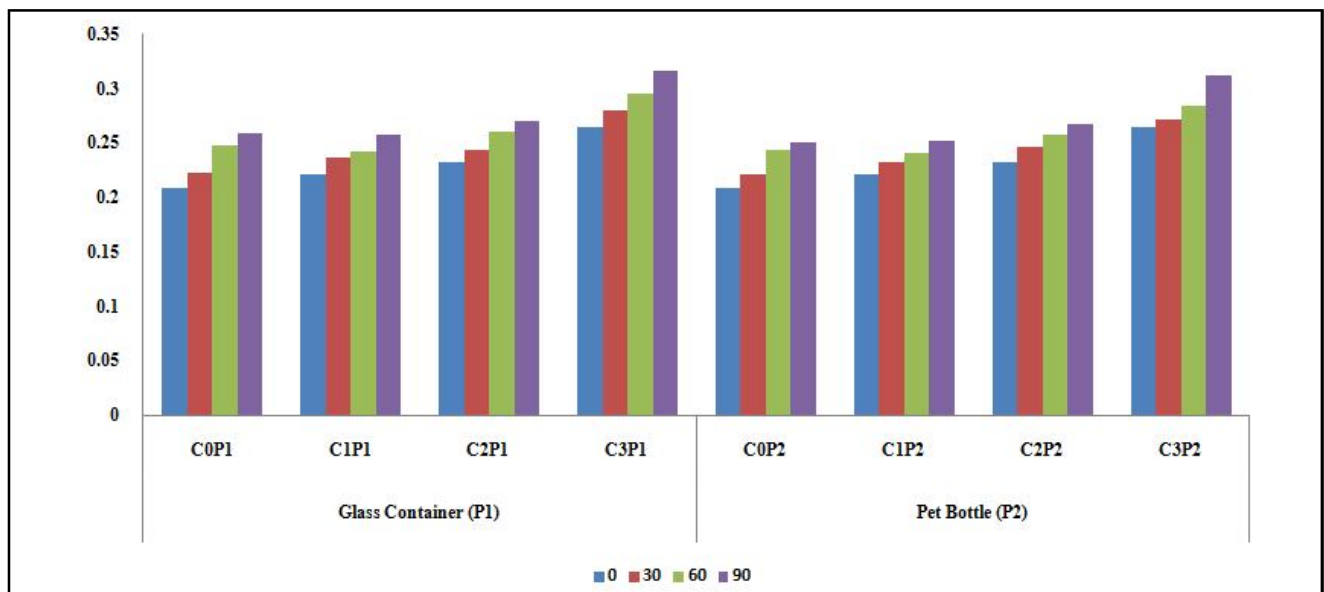


Figure 3: Non enzymatic browning (absorbance) of jam from Indian mulberry fruit blended with other fruits.

3.8 Non-enzymatic browning (NEB)

Table 8 and Figure 3 presents the changes in non enzymatic browning of Indian mulberry jam and the control during the 90 day storage period. All jam samples exhibited a gradual increase in non enzymatic browning over time, reflected by a progressive darkening of color.

The type of packaging material influenced the extent of browning, with some samples showing slightly higher values depending on the container. Statistical analysis indicated a significant increase in non enzymatic browning with storage duration, packaging type, and storage temperature.

Table 9: Organoleptic characteristics of Indian mulberry incorporated jam

Quality attributes	Storage period	(P ₁)				(P ₂)			
		C ₀ P ₁	C ₁ P ₁	C ₂ P ₁	C ₃ P ₁	C ₀ P ₂	C ₁ P ₂	C ₂ P ₂	C ₃ P ₂
Colour and appearance	0	8.30 ± 0.13	8.80 ± 0.23	9.60 ± 0.00	8.50 ± 0.18	8.30 ± 0.05	8.80 ± 0.16	9.60 ± 0.26	8.50 ± 0.06
	30	8.31 ± 0.15	8.82 ± 0.15	9.63 ± 0.30	8.51 ± 0.19	8.30 ± 0.24	8.84 ± 0.25	9.61 ± 0.27	8.51 ± 0.05
	60	8.34 ± 0.07	8.85 ± 0.16	9.65 ± 0.22	8.58 ± 0.26	8.32 ± 0.11	8.86 ± 0.07	9.63 ± 0.30	8.54 ± 0.09
	90	8.37 ± 0.26	8.88 ± 0.14	9.69 ± 0.22	8.63 ± 0.22	8.34 ± 0.26	8.89 ± 0.09	9.64 ± 0.09	8.61 ± 0.19
Flavour	0	5.40 ± 0.02	7.60 ± 0.25	6.40 ± 0.10	8.30 ± 0.12	5.40 ± 0.17	7.60 ± 0.17	6.40 ± 0.06	8.30 ± 0.13
	30	5.38 ± 0.003	7.56 ± 0.22	6.37 ± 0.12	8.27 ± 0.16	5.39 ± 0.00	7.58 ± 0.22	6.39 ± 0.01	8.29 ± 0.02
	60	5.37 ± 0.04	7.55 ± 0.21	6.34 ± 0.12	8.25 ± 0.08	5.37 ± 0.17	7.57 ± 0.23	6.36 ± 0.18	8.27 ± 0.11
	90	5.30 ± 0.093	7.51 ± 0.02	6.33 ± 0.03	8.23 ± 0.24	5.35 ± 0.08	7.53 ± 0.13	6.34 ± 0.15	8.24 ± 0.24
Consistency	0	8.00 ± 0.04	8.90 ± 0.07	9.50 ± 0.20	8.90 ± 0.12	8.00 ± 0.21	8.90 ± 0.12	9.50 ± 0.014	8.90 ± 0.29
	30	7.96 ± 0.05	8.85 ± 0.09	9.45 ± 0.30	8.83 ± 0.09	7.97 ± 0.18	8.88 ± 0.28	9.47 ± 0.30	8.86 ± 0.09
	60	7.92 ± 0.07	8.82 ± 0.28	9.41 ± 0.17	8.78 ± 0.25	7.94 ± 0.10	8.87 ± 0.06	9.45 ± 0.16	8.85 ± 0.00
	90	7.88 ± 0.08	8.78 ± 0.00	9.38 ± 0.11	8.76 ± 0.05	7.91 ± 0.20	8.83 ± 0.18	9.41 ± 0.03	8.83 ± 0.12
Taste	0	6.50 ± 0.18	7.80 ± 0.17	7.50 ± 0.15	8.50 ± 0.24	6.50 ± 0.05	7.80 ± 0.00	7.50 ± 0.17	8.50 ± 0.16
	30	6.46 ± 0.18	7.77 ± 0.04	7.48 ± 0.05	8.46 ± 0.20	6.49 ± 0.03	7.78 ± 0.19	7.49 ± 0.18	8.48 ± 0.19
	60	6.44 ± 0.06	7.75 ± 0.10	7.43 ± 0.15	8.41 ± 0.10	6.46 ± 0.09	7.77 ± 0.15	7.46 ± 0.13	8.45 ± 0.14
	90	6.41 ± 0.09	7.73 ± 0.20	7.39 ± 0.11	8.38 ± 0.17	6.44 ± 0.17	7.74 ± 0.01	7.43 ± 0.16	8.41 ± 0.14
Overall acceptability	0	6.20 ± 0.10	7.90 ± 0.16	7.20 ± 0.00	7.90 ± 0.22	6.20 ± 0.11	7.90 ± 0.25	7.20 ± 0.24	7.90 ± 0.04
	30	6.16 ± 0.10	7.86 ± 0.03	7.14 ± 0.03	7.86 ± 0.16	6.18 ± 0.08	7.87 ± 0.10	7.17 ± 0.20	7.88 ± 0.02
	60	6.12 ± 0.05	7.82 ± 0.12	7.08 ± 0.00	7.83 ± 0.08	6.15 ± 0.05	7.83 ± 0.02	7.13 ± 0.10	7.87 ± 0.16
	90	6.02 ± 0.14	7.79 ± 0.16	7.03 ± 0.22	7.81 ± 0.09	6.12 ± 0.09	7.81 ± 0.05	7.09 ± 0.02	7.83 ± 0.14

3.9 Organoleptic characteristics of Indian mulberry incorporated jam

Changes in physicochemical quality parameters during storage directly influenced the organoleptic attributes of Indian mulberry jam including color, appearance, flavor, texture, taste and overall acceptability. With increasing storage duration, slight variations were observed in color, appearance and flavor, which marginally affected sensory perception. The sensory evaluation data presented in the table indicate that both glass botke (P₁) and PET bottle (P₂) packaged samples stored at room temperature exhibited minimal deterioration in overall quality throughout the storage period. Among the different formulations the Indian mulberry with orange jam consistently received the highest sensory scores followed by Indian mulberry with amla, Indian mulberry with sathukkudi and Indian mulberry for all evaluated attributes in both packaging materials. A gradual

intensification of characteristic Indian mulberry flavor was noted with extended storage irrespective of packaging type or storage condition without adversely affecting overall acceptability (Table 9).

The overall acceptability scores of the Indian mulberry incorporated jam was highly influenced by the colour and appearance, body, flavor and taste. From the results it was found that the Indian mulberry incorporated with amla jam (Indian mulberry with orange) had the higher organoleptic score values followed by Indian mulberry with sathukkudi, Indian mulberry with amla and Indian mulberry.

3.10 Microbial changes of the Indian mulberry incorporated jam

The microbial quality of Indian mulberry jam blended with other fruits is presented in Table 10. A gradual increase in microbial load

was observed in all samples during storage, particularly in those stored at room temperature in both glass bottle (P_1) and PET bottle (P_2). Yeast counts showed a slight increase over the storage period; however, the levels remained within acceptable limits. Initial fungal growth was detected in samples Indian mulberry, Indian mulberry with amla and Indian mulberry with orange at approximately 1×10^{-4} cfu/ml when stored at room temperature in both packaging

materials, whereas no fungal growth was observed in the Indian mulberry with amla sample during the early storage period. After 90 days of storage, fungal growth in Indian mulberry increased to approximately 2×10^{-4} cfu/ml, while samples stored in both glass and PET bottles showed fungal counts of around 1.0×10^{-4} cfu/ml. Overall, the results indicate a slight increase in microbial load with storage duration, influenced by packaging type and storage conditions.

Table 10: Microbial changes of the Indian mulberry incorporated jam during storage

Particulars	Storage period (days)	(P_1)				(P_2)			
		C_0P_1	C_1P_1	C_2P_1	C_3P_1	C_0P_2	C_1P_2	C_2P_2	C_3P_2
Bacterial $\times 10^{-6}$ cfu/g	0	3.0 ± 0.02	2.0 ± 0.03	2.0 ± 0.03	2.0 ± 0.04	3.0 ± 0	2.0 ± 0.03	2.0 ± 0.05	2.0 ± 0.03
	90	5.0 ± 0.12	2.0 ± 0.00	2.0 ± 0.01	3.0 ± 0.00	6.0 ± 0.019	2.0 ± 0.01	3.0 ± 0.02	3.0 ± 0
Yeast $\times 10^{-3}$ cfu/g	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	90	3.0 ± 0.03	2.0 ± 0.02	2.0 ± 0.02	3.0 ± 0.09	3.0 ± 0.01	1.0 ± 0.01	1.0 ± 0.02	2.0 ± 0.06
Fungi $\times 10^{-4}$ cfu/g	0	1.0 ± 0.02	0.0	1.0 ± 0.01	0.0	1.0 ± 0.02	0.0	1.0 ± 0.00	0.0
	90	2.0 ± 0.04	1.0 ± 0.00	1.0 ± 0.03	1.0 ± 0.02	2.0 ± 0.00	1.0 ± 0.00	1.0 ± 0.00	1.0 ± 0.01

4. Discussion

The present study demonstrated that Indian mulberry fruit can be effectively utilized for the preparation of value-added incorporated jams by blending with amla, sathukkudi and orange resulting in improved sensory acceptability while retaining nutritional and functional quality. The observed physicochemical, sensory and microbial changes during 90 days of ambient storage were consistent with the inherent composition of Indian mulberry fruit and the applied processing and packaging conditions.

A gradual increase in pH was observed in all jam formulations during storage. The pH of the control Indian mulberry jam increased from 3.31 to 3.49 in glass bottles and from 3.31 to 3.43 in PET bottles over 90 days, while blended formulations showed comparatively higher pH values, particularly Indian mulberry with amla (4.31 to 4.52). This increase in pH corresponded with a decline in titratable acidity, which decreased from 1.18% to 1.02% in the control and from 1.42% to 1.29% in Indian mulberry with amla jam stored in glass containers. Similar reductions were observed in PET bottles. These changes may be attributed to the partial utilization or neutralization of organic acids during storage and sugar acid interactions. Comparable trends have been reported in Indian mulberry and other fruit preserves during ambient storage (Potterat and Hamburger, 2017; Mathivanan *et al.*, 2019). The slightly higher acid retention in glass bottles suggests better barrier properties against oxygen diffusion.

Total soluble solids (TSS) remained relatively stable throughout the storage period in all samples ranging from 68.0 to 68.6°Brix. The control jam showed a marginal increase from 68.0 to 68.2°Brix, while Indian mulberry with orange increased from 68.5 to 68.6°Brix in glass bottles. This stability indicates effective processing to the recommended endpoint for jam preparation and confirms minimal moisture migration or degradation of soluble solids during storage, supporting earlier findings in processed Indian mulberry products (West *et al.*, 2011).

Reducing sugar content increased progressively during storage, while total sugars showed a slight decline. In the control jam reducing

sugars increased from 6.06 to 6.83 g/100 g in glass bottles, whereas total sugars decreased from 58.30 to 57.36 g/100 g. A similar trend was observed in blended formulations with Indian mulberry with amla showing reducing sugars increasing from 8.15 to 8.71 g/100 g. This pattern can be attributed to the acid-mediated hydrolysis of sucrose into glucose and fructose, a phenomenon widely reported in fruit preserves during storage (Ranganna, 1977; Mathivanan *et al.*, 2005).

Ascorbic acid content declined significantly in all formulations during storage. In the control jam, vitamin C decreased from 18.76 to 16.21 mg/100 g in glass bottles and from 18.76 to 16.88 mg/100 g in PET bottles. Among blended jams, Indian mulberry with orange retained higher levels, decreasing from 20.63 to 19.08 mg/100 g in glass containers. The higher retention observed in amla and orange blended jams reflects the naturally high vitamin C content of these fruits (Almeida *et al.*, 2019). The observed losses are consistent with the sensitivity of ascorbic acid to oxygen, light and storage duration, as reported earlier for Indian mulberry based products (Inada *et al.*, 2017; West *et al.*, 2011).

Tannin content showed a decreasing trend during storage in all samples. The control jam showed a reduction from 0.716% to 0.611% tannic acid in glass bottles, while Indian mulberry with amla decreased from 0.830% to 0.723%. The reduction in tannins may be attributed to oxidation, polymerization and precipitation reactions during storage. From a sensory standpoint this reduction is beneficial as tannins contribute to bitterness and astringency, which are undesirable characteristics of Indian mulberry based products (Potterat and Hamburger, 2007).

Non-enzymatic browning increased progressively during storage as indicated by absorbance values. In the control jam, browning increased from 0.208 to 0.259 in glass bottles, while Indian mulberry with orange showed a higher increase from 0.265 to 0.317. This increase can be attributed to Maillard reactions between reducing sugars and amino acids, as well as caramelization reactions. Indian mulberry fruit is rich in amino acids and sugars, which can accelerate browning reactions during storage (West *et al.*, 2011; Wang *et al.*, 2021).

Sensory evaluation revealed that fruit incorporation significantly enhanced acceptability. Indian mulberry with orange jam consistently received the highest scores for flavor (8.30 to 8.23), taste (8.50 to 8.38) and overall acceptability (7.90 to 7.81) over the storage period, followed by Indian mulberry with amla. The control jam recorded comparatively lower scores, particularly for flavor (5.40 to 5.30), due to the characteristic pungency of Indian mulberry. These findings confirm that citrus and amla blending effectively masked the undesirable sensory attributes of Indian mulberry, as previously reported (Mathivanan *et al.*, 2019; Singh and Sharma, 2020).

Microbiological analysis showed that all jam samples remained within permissible limits throughout storage. Bacterial counts increased marginally from 3×10^{-6} to 5 to 6×10^{-6} cfu/g in the control, while yeast and fungal counts remained low. The high TSS, acidic pH and use of preservatives contributed to microbial stability confirming the safety of the products during storage (Ranganna, 1977).

Beyond nutritional quality, the functional relevance of Indian mulberry based jams can be attributed to the presence of bioactive compounds inherent to Indian mulberry. The fruit contains phenolic acids such as chlorogenic acid, gentisic acid and p-hydroxybenzoic acid, which exhibit strong antioxidant and free-radical scavenging activities (Inada *et al.*, 2017; Su *et al.*, 2005). Phenylpropanoids and iridoid glycosides, including noniosides A-H, contribute to anti-inflammatory, hepatoprotective and immunomodulatory effects and are reported to remain stable under acidic processing conditions (Wang *et al.*, 2011; Almeida *et al.*, 2019).

Indian mulberry fruit polysaccharides have been shown to reduce oxidative stress and inflammation by enhancing endogenous antioxidant enzymes such as catalase and glutathione peroxidase (Yang *et al.*, 2020). Phytosterols such as β -sitosterol-3-O- β -D-glucopyranoside further contribute cholesterol lowering and anti-inflammatory effects (Saludes *et al.*, 2002). The partial retention of vitamin C, phenolics and tannins observed in this study indicates that Indian mulberry incorporated jams can act as effective carriers of health-promoting bioactive compounds. Overall, the results confirm that appropriate fruit incorporation and controlled processing can mitigate the sensory limitations of Indian mulberry while preserving its nutritional and functional attributes thereby enhancing its potential for commercialization as a functional fruit preserve.

5. Conclusion

The present study clearly demonstrates that Indian mulberry fruit can be successfully utilized for the development of value-added incorporated jams by blending with amla, sathukkudi and orange thereby improving sensory acceptability while retaining nutritional quality. The optimum blending ratios identified were Indian mulberry with amla (60:40), Indian mulberry with sathukkudi (70:30) and Indian mulberry with orange (80:20). During 90 days of ambient storage all jam formulations exhibited a gradual increase in pH (3.31 to 3.49) and reducing sugars (6.06 to 6.83 g/100 g) along with a corresponding decrease in titratable acidity (1.18 to 1.02%), total sugars, ascorbic acid (18.76 to 16.21 mg/100 g) and tannin content (0.716 to 0.611%) indicating normal storage-related biochemical changes. Total soluble solids remained stable at approximately 68.0 to 68.6°Brix confirming effective processing and moisture stability, while non-enzymatic browning showed a progressive increase

throughout storage. Among the formulations, Indian mulberry blended with orange and amla retained higher vitamin C levels and received significantly higher sensory scores for flavour, taste and overall acceptability with orange blended jam recording the highest acceptability (7.90 to 7.81). Packaging material influenced quality retention with glass bottles showing better acidity stability and PET bottles marginally improving ascorbic acid retention. Microbiological analysis revealed only a slight increase in bacterial, yeast and fungal counts all remaining within permissible limits up to 90 days. Finally, the findings confirm that strategic fruit incorporation effectively masks the undesirable sensory attributes of Indian mulberry while preserving its nutritional and functional properties, highlighting the strong potential of Indian mulberry incorporated jams for commercialization as safe, shelf-stable and consumer acceptable functional fruit preserves.

Acknowledgements

The authors are highly grateful to Tamil Nadu Agricultural University, Coimbatore for resources.

Conflict of interest

The authors declare no conflicts of interest relevant to this article.

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Citation

J. Selvi, L. Karpagapandi, V. Meenakshi, J. Thilagam, S. Krishnakumar and R. Packiyalakshmi (2025). Studies on quality evaluation of Indian mulberry (*Morinda citrifolia* L.) incorporated fruit jam. Ann. Phytomed., **14**(2):504-514. <http://dx.doi.org/10.54085/ap.2025.14.2.49>.