Tropical Agricultural Research & Extension 28 (4): 2025

RESEARCH ARTICLE

DEVELOPMENT OF COCONUT-BASED NON-DAIRY ICE CREAM USING UNDERUTILIZED SRI LANKAN FRUITS AND EVALUATION OF ITS SENSORY AND PHYSICOCHEMICAL PROPERTIES

Samarasinghe SANP[1], Fernando GSN[1], Amarathunga YN[2], de Silva PGSM[3], Silva ABG[2*], Wickramasekara TD[2], and Pathirage S[4]

[1]Department of Food Science and Technology, Faculty of Agriculture, University of Ruhuna, Mapalana, Kamburupitiya, Sri Lanka

[2]Department of Nutrition, Medical Research Institute, Colombo 08, Sri Lanka

[3]Department of Electron Microscopy, Medical Research Institute, Sri Lanka

[4]Department of Food and Water, Medical Research Institute, Colombo 08, Sri Lanka

Received: 12 October 2025; Accepted: 08 December 2025; Published: 31 December 2025

ABSTRACT

The growing demand for dairy-free frozen desserts has encouraged the development of plant-based ice creams with improved nutritional and functional qualities. This study developed a coconut milk–based vegan ice cream incorporating soursop (*Annona muricata*) and Ceylon olive (*Elaeocarpus serratus*) and evaluated its sensory, proximate, physicochemical, functional, and storage properties comparison with a control. Four formulations with different soursops to Ceylon olive puree ratios were prepared: T1 (1:1), T2 (1:2), T3 (2:1), and T4 (0:0 control). Sensory evaluation with 50 untrained panelists on a 5-point hedonic scale identified T1 (1:1) as the most preferred formulation. Proximate analysis of T1 revealed 55.67 ± 0.84 g/100 g moisture, 1.29 ± 0.01 g/100 g protein, 0.55 ± 0.00 g/100 g fiber, 23.00 ± 1.78 g/100 g carbohydrate, 19.09 ± 0.34 g/100 g fat, and 0.73 ± 0.07 g/100 g ash. Functional analysis showed significantly higher antioxidant activity (542.14 ± 11.00 mg TE/100 g), flavonoid content (725.00 ± 22.05 mg QE/100 g), and total phenolic content (334.33 ± 9.38 mg GAE/100 g) than the control ($p < 0.05$). During one month of storage at −18 °C, T1 showed a pH reduction from 4.42 ± 0.01 to 3.86 ± 0.02, total soluble solids increased from 23.27 ± 0.75 to 26.87 ± 0.61 Brix, and titratable acidity rose from 0.72 ± 0.06% to 1.22 ± 0.06%, compared with the control. Microbiological analyses was assessed biweekly for two months under the same conditions confirming the product safety, with total plate count decreasing from 5×10^3 CFU/g initially to less than 1×10^3 CFU/g, while presumptive coliforms, *Salmonella* spp. and *Escherichia coli* were absent. It can be concluded that the developed product represents a safe and promising plant-based frozen dessert alternative with enhanced fiber, fat, and functional properties.

Keywords: Ceylon olive puree, Coconut base, Non-dairy ice cream, Sensory properties, Soursop puree

INTRODUCTION

Ice cream is a favourite frozen dessert enjoyed by people of all ages around the world. In particular, during the warm season, it gains more popularity due to its refreshing coolness (Perera and Perera, 2021; Ademosum, 2021; Pinandoyo *et al.,* 2021). Despite its popularity, traditional dairy ice cream is often considered a nutritionally limited dessert because it provides low levels of essential micronutrients, such as vitamins, minerals, and bioactive compounds like antioxidants and phenolics (Rawendra and Dawi, 2020).

In recent years, global consumer trends have shifted towards foods with measurable health attributes, including lower glycemic impact, reduced calorie density, and higher antioxidant content. According to Grand View Research (2023), health and wellness concerns are strongly influencing consumer purchasing decisions, driving demand for vegan, dairy-free alternatives. This demand is

Corresponding author: buddhikagayani@yahoo.com

further driven by concerns regarding dairy-related allergies, lactose intolerance and the environmental footprint associated with animal -based products (Mäkinen *et al.,* 2016; Poore and Nemecek, 2018; Geburt *et al.,* 2022; Rehal, Thapa and Kaushal, 2025). Mäkinen *et al.* (2016) reported that approximately 75% of the global population experiences lactose intolerance, highlighting the importance of non -dairy alternatives.

Plant-based ice creams are typically formulated using bases such as soy, almond, cashew, coconut, yams or rice milk, each offering distinct functional and nutritional advantages (Patil, 2024). Among these, coconut milk stands out as a suitable option due to its rich lipid profile, affordability, widespread availability in tropical regions and its ability to deliver a creamy mouthfeel comparable to dairy fat (Jayasundera *et al.,* 2014; Góral *et al.,* 2018; Perera & Perera, 2021). However, compared to extensively studied non-dairy bases such as soy milk, coconut milk-based ice creams remain relatively underexplored, indicating opportunities for further product development (Rawendra and Dawi, 2020).

According to Ranawake (2021), many underutilized food resources exist in the wet-zone forests of Sri Lanka. Furthermore, Sri Lanka is home to more than 60 varieties of underutilized fruits (Dahanayake, 2015), including Soursop (*Annona muricata*) and Ceylon olive (*Elaeocarpus serratus*). These fruits contribute vitamins, minerals, dietary fiber and bioactive compounds offering antioxidant, anti-inflammatory, antidiabetic, antimicrobial and antihypertensive properties (Akomolafe & Ajayi, 2015; Mutakin *et al.,* 2022; Nakandalage & Anuruddi, 2023). Although abundant, these fruits remain largely underused in commercial food processing, leading to significant post-harvest losses during peak seasons. Integrating such fruits into plant-based ice cream can enhance nutritional value, reduce post-harvest losses, and support local agricultural livelihoods, thereby contributing to national food and nutrition security (Ariyasoma & Wathugala, 2023).

Sweeteners also play a critical role in the sensory quality of ice cream. Refined sugar, the traditional sweetening agent, contributes to high glycemic load and excessive caloric intake. To address these concerns, this study replaces refined sugar with *kithul* treacle (*Caryota urens*), a Sri Lankan natural sweetener known for its mineral content, antioxidant activity and low glycemic index (Weeraratne and Ekanayake, 2022; Dulmini and Perera, 2024). Moreover, its distinctive caramel-like flavour enhances product acceptability.

Although previous studies have investigated non-dairy ice cream formulations and fruit-based enrichment independently, research combining underutilized Sri Lankan fruits with coconut milk and natural low-GI sweeteners remains extremely limited, with only a few related attempts reported (Mulwa *et al.*, 2023; Roshana *et al.,* 2025). Most functional ice cream studies continue to focus on commonly available fruits, often using refined sugar, limiting their overall nutritional appeal.

Therefore, this study is the first to develop a lactose-free ice cream using coconut milk enriched with Soursop and Ceylon olive fruits and sweetened with *Kithul* treacle. The product was evaluated for proximate composition, physicochemical properties, functional characteristics and sensory acceptability. The findings provide baseline data for the development of nutrient-dense, sustainable and commercially viable plant-based frozen desserts in Sri Lanka and other tropical regions.

MATERIALS AND METHODS

Raw materials

The main raw materials used to prepare the vegan ice cream were sourced from local supermarkets and fruit vendors in the Gampaha District, Sri Lanka. Fresh soursop (*A. muricata*) and Ceylon olive (*E. serratus*) were selected at optimal maturity. Fruits were stored under refrigerated conditions (4±2 °C), and all other raw materials were stored under room temperature (30±2 °C) until further use. All chemicals and reagents used in the experiments were of analytical grade.

Preparation of coconut milk and cream
Coconut scrapes were blended with drinking water at a 1:3 (w/v) ratio to extract coconut milk. The mixture was filtered through muslin cloth and kept in the refrigerator (4±2 °C) for 4 hours to separate the cream by gravity. The coconut milk and cream were recombined in a 1:3 (v/v) ratio before use in the formulation.

Preparation of fruit puree
Fresh fruits were thoroughly washed under running water, peeled, and deseeded. The fruit pulp of Soursop and Ceylon olive was separately blended into a smooth puree using a blender (BL456AB-G, Abans PLC, China). The purees were stored in sterile food-grade containers under refrigeration (4±2 °C) before incorporation into the ice cream mix. Purees were used within two days to ensure freshness.

Preparation of different ice cream formulations
Preliminary trials were conducted with a fifty untrained sensory panel to refine the ice cream formulation before treatment preparation. A coconut milk-to-cream ratio of 1:3 (v/v) was identified as the most suitable base, and incorporation of xanthan gum (0.15%) improved texture and smoothness. The finalized formulation of Soursop–Ceylon olive with coconut milk and cream was used to develop subsequent treatments.

Formulation of treatments
Based on the preliminary studies, four treatments were prepared by varying the ratio of Soursop to Ceylon olive, while keeping coconut milk, *kithul* treacle, and stabilizer constant (Table 1-A and B). Fruit pulp was incorporated into the ice cream base by replacing an equivalent amount of water to maintain the total mixture weight and solids content across all treatments.

Table 1-A: Fruit treatments in ice cream

Treatment	Soursop %	Ceylon Olive %	Soursop: Ceylon olive
T1	11.36	11.36	1:1
T2	7.57	15.16	1:2
T3	15.16	7.57	2:1
T4 (Control)	0.00	0.00	0:0

Preparation of non-dairy ice cream
The preparation process followed a standard non-dairy ice cream manufacturing method described by Mulwa *et al.,* (2023) with modifications. Ice cream mixtures were pasteurized at 85 °C for 5 minutes, cooled to 4 °C, and aged for four hours. Aged mixtures were whipped using a mixer (MK-H100N, Panasonic Corporation, Japan), frozen for 1 hour and then repeated three times.

Sensory evaluation of developed non-dairy ice cream formulations
A sensory evaluation was conducted using 50 untrained panelists. Approximately 10 mL (one scoop) of each formulation was served to panelists in coded, randomized portions at (30 ± 2 °C) after 24 hours of manufacturing. Samples were presented in disposable, odor-free plastic cups labeled with three-digit random codes. Panelists were instructed to cleanse their palate with water between samples. A five-point hedonic scale (1 = dislike very much, 5 = like very much) was used to evaluate color, taste, texture, aroma, and overall acceptability. The best formulation was selected based on the highest mean hedonic scores and statistical significance ($p < 0.05$).

Analysis of physicochemical properties
All analyses followed standard protocols, with three replicates for the selected and control samples.

Determination of pH
The pH was determined for both selected ice cream samples and control samples using a calibrated pH meter (HI 99161, Romania) at room temperature (30±2 ℃) following the principles of AOAC 981.12 with modifications (Association of Official Analytical Chemists, 1984).

Table 1-B: Ice cream base formulation (constant for all treatments)

Ingredient	Percentage %
Coconut milk + Cream	57.95
Kithul treacle	19.20
Xanthan gum	0.15

Determination of total soluble solids content

The total soluble solids (TSS) content of selected ice cream samples and control sample were determined utilizing a digital refractometer (model XYZ123, Japan).

Determination of titratable acidity

The titratable acidity was determined using a standardized 0.1N sodium hydroxide solution, taking 10 g of each sample, adding 90 ml of distilled water, and using phenolphthalein as the indicator. Acidity was expressed as a percentage of lactic acid (1 mL of 0.1N NaOH = 0.009 g lactic acid (Fiol *et al.,* 2016).

Proximate analysis

The proximate composition of the developed ice cream sample and control sample was tested using the methods described by the Association of Official Analytical Chemists (AOAC), such as moisture content (925.10), crude fat (2003.05), crude fiber (978.10), crude protein (2001.11) and total ash content (923.03) (AOAC, 2019). Carbohydrate content was determined by subtracting the sum of moisture, crude fat, crude protein, crude fiber, and total ash content of the sample from 100 g (FAO, 2003).

Analysis of bioactive properties

Preparation of extract

The extract was prepared using **70% (v/v) aqueous methanol** following the method described by Perera and Perera (2021) with slight modifications. The 1 g of oven-dried sample was mixed with 10 mL of 70% methanol and stirred in a shaking water bath at 200 rpm for 2 hours at room temperature (30 ± 2 °C). The mixture was centrifuged at 3500 rpm for 10 minutes (HERMLE Labortechnik GmbH, Z306, Germany), and the supernatant was collected. The extract was filtered, and the process was repeated two more times. Supernatants were combined and stored at −18 °C until further analysis for total phenolic content determination, extracts were prepared separately using 95% (v/v) methanol, following the same extraction procedure.

Determination of total flavonoid content

The total flavonoid content of the ice cream extract was determined using the aluminium chloride colourimetric method according to the procedure of Saha et al. (2023), with slight modifications. Quercetin was used as the standard. Volumes of 2 mL of diluted methanolic sample fractions, quercetin standard solutions, and a blank solution of distilled water were prepared. From the extract, 0.4 mL was transferred into a volumetric flask and 1.6 mL of distilled water was added. Next, 0.16 mL of 5% $NaNO_2$ was added, and the mixture was left to stand for 15 minutes. Then, 0.24 mL of 10% AlCL3 was added, followed by 0.8 mL of 1 M NaOH. The final volume was adjusted to 4 mL with distilled water. Then, the solution was vortexed for 30 seconds using a vortex (ZX3, VELP SCIENTIFICA, Italy) and incubated at room temperature (30 ± 2 °C) for 1 hour. Absorbance was measured at 510 nm using a double-beam UV-visible spectrophotometer (CT-8600, Chrom Tech, Taiwan). The total flavonoid content was expressed as milligrams of quercetin equivalents per 100 g of dried sample (mg QE/100 g).

Determination of total antioxidant activity by DPPH assay

The antioxidant activity of the ice cream extract was measured using the DPPH radical-scavenging assay, following the procedure described by Fernando et al. (2022) with minor modifications. A 0.1 mM DPPH solution was prepared as the stock solution, and 60% (v/v) methanol was used as the control. For the test samples, 0.4 mL of the methanolic extract was mixed with 4 mL of the 0.1 mM DPPH stock solution, then thoroughly vortexed (ZX3, VELP SCIENTIFICA, Italy) and incubated in the dark at room temperature (30 ± 2 °C) for 30 minutes. The absorbance was recorded at 517 nm using a double-beam UV-visible spectrophotometer (CT-8600, Chrom Tech, Taiwan). Trolox was used as the standard. Antioxidant activity was expressed as milligrams of Trolox equivalents per 100 g of dried sample (mg TE/100 g).

Determination of total phenolic content

Total phenolic compounds in the ice cream extract were determined by the method described by Chandra *et al*. (2014), with slight modifications. Two hundred microliters (200 µL) of the ice cream extract were prepared in 95% (v/v) methanol, and the blank was prepared in distilled water. Then, to the extract, 0.8 mL of Folin-Ciocalteu reagent, which was diluted eightfold with distilled water was added, followed by 3 mL of 4% (w/v) sodium bicarbonate solution to terminate the reaction by alkalinizing. The mixture was incubated in the dark at room temperature (30 ± 2 °C) for 30 minutes. Absorbance was measured at 765 nm using a double-beam UV-visible spectrophotometer (CT-8600, Chroma Tech, China). Total phenolic content was expressed as mg of Gallic acid equivalent per 100 g of the sample.

Analysis of the shelf-life of the developed product

Shelf life was determined by using both physicochemical and microbiological parameters. Physicochemical parameters such as pH, titratable acidity, and Brix value were measured weekly for one month, and microbial parameters such as aerobic plate count, presumptive *coliforms*, *Escherichia coli, Staphylococcus aureus*, *Salmonella* spp., and *Bacillus cereus* were measured bi-weekly for two months. All the samples were stored in sterile food-grade tubs at -18 °C**.**

Analysis of physicochemical properties during storage

The same procedures were followed that are described in 3.5 section to determine pH (AOAC 981.12), total soluble solids content and titratable acidity (Fiol *et al.,* 2016). All parameters were analyzed weekly for one month for the and control samples with three replicates.

Microbiological analysis during storage

Microbiological parameters were measured only for the developed product bi-weekly for two months. All procedures were in accordance with the respective SLS and ISO standards.

Preparation of sample and dilution series

Ten grams of ice cream was aseptically weighed and transferred into a sterile Stomacher bag containing 100 mL of 0.1% buffered peptone water and homogenized using Stomacher Blender. Serial dilutions were prepared and used for microbial enumeration.

Determination of aerobic plate count (APC)

Enumeration of aerobic microorganisms was performed in accordance with SLS 516: Part 1:2013 / ISO 4833-1:2013. Plate count agar was prepared, sterilized at 121 °C for 20 minutes, and cooled to 45 °C. The pour plate method was used, and plates were incubated at 30 ± 2 °C for 24 hours. Colonies were then counted.

Determination of presumptive *coliform* count

Coliforms were enumerated according to SLS 614:2013 / ISO 4832:2006.

Determination of *Escherichia coli* count

E. coli detection was performed following SLS 516: Part 12:2013 / ISO 7251:2005. One milliliter of the sample dilution was inoculated onto *E. coli* petri films and incubated at 33–35 °C for 24–48 hours. Colonies were then enumerated.

Determination of *Staphylococcus aureus*

Detection of *S. aureus* followed SLS 516: Part 1:2013 / ISO 6888-1:2022. Baird-Parker agar supplemented with egg yolk was prepared and sterilized. A 10 g ice cream sample was blended in 100 mL of buffered peptone water using a Stomacher blender (Stomacher 3500 Jumbo, UK), then diluted, plated, and incubated at 35 ± 0.5 °C for 24–48 hours. Colonies were counted.

Determination of *Salmonella* spp.

Salmonella detection followed SLS 516: Part 5:2011 / ISO 6579-1:2017. Pre-enrichment was done in 1% buffered peptone water, followed by selective enrichment in Rappaport–Vassiliadis broth, and plating on XLD /SS/MacConkey agar. Plates were incubated according to the standard protocol.

Determination of *Bacillus cereus*

Enumeration followed SLS 516: Part 8:2013 / ISO 7932:2004. Ten grams of ice cream was homogenized in buffered peptone water, plated on mannitol-egg yolk-polymyxin agar, and incubated at 37 °C for 24 h. Colonies were observed and counted.

Statistical analysis

All the data are presented as mean ± standard deviation (SD) of three replicates. Data were analyzed by one-way ANOVA & Tukey's test was applied to determine the statistical significance among the different groups at $p<0.05$ using SPSS software Version 23.0 for Windows.

RESULTS AND DISCUSSION

Sensory evaluation of ice cream samples

The sensory evaluation offered a clear understanding of the consumer-perceived quality of the ice cream samples across key attributes (Table 2).

The sample T1 (Soursop: Ceylon olive; 1:1 w/ w) emerged as the most preferred formulation in terms of taste, texture, aroma, and overall acceptability. It achieved the highest mean sensory scores (Table 2). In contrast, sample T4 (control sample), without fruits, received the lowest scores across evaluated attributes, with significantly reduced overall acceptability ($P < 0.05$) except for colour values. Samples T2 and T3 were similarly well accepted for texture while T3 additionally received higher ratings for aroma. No significant difference was observed in colour among all four samples. Based on these findings, sample T1 was selected for further analyses along with the control sample. The higher consumer preference for T1 can be attributed to the balanced flavor contribution of Soursop, Ceylon olive and coconut milk, which masked the strong astringency of fruit purees and enhanced the overall sensory appeal. This result is in agreement with previous studies demonstrating that the incorporation of fruit purees into plant-based or dairy-free ice cream enhances sensory attributes such as flavor, texture, and overall acceptability (Perera and Perera, 2021; Bajwa *et al.,* 2003).

Table 2: **Mean rank value of sensory evaluation of four treatment combinations**

Attribute	Treatments			
	T1	T2	T3	T4
Colour	3.62 ± 0.74^{a}	3.56 ± 0.70^{a}	3.74 ± 0.67^{a}	3.62 ± 0.70^{a}
Taste	4.06 ± 0.79^{a}	3.70 ± 0.69^{ab}	3.90 ± 0.67^{ab}	3.56 ± 0.71^{b}
Texture	4.16 ± 0.76^{a}	3.98 ± 0.78^{a}	3.88 ± 0.77^{a}	2.68 ± 0.76^{b}
Aroma	3.98 ± 0.63^{a}	3.76 ± 0.64^{ab}	3.96 ± 0.64^{a}	3.46 ± 0.68^{b}
Overall acceptability	4.04 ± 0.66^{a}	3.82 ± 0.64^{a}	4.00 ± 0.62^{a}	3.36 ± 0.66^{b}

Soursop: Ceylon olive ratios (T1: 1:1, T2: 1:2, T3: 2:1, T4: 0:0). Values with different superscripts in the same column are significantly different at $p < 0.05$.

Proximate composition of developed ice cream and control sample

The assessment of the proximate composition of the developed ice cream revealed notable differences compared to the control, providing valuable insights into its nutritional profile. The results of the developed ice cream and the control sample are shown in Table 3.

Table 3: Comparison of proximate composition of the developed ice cream sample (T1) and the control sample

Parameter (g/ 100 g)	Developed an ice cream sample (T1)	Control sample
Moisture	55.67 ± 0.84^{a}	53.70 ± 0.35^{b}
Protein	1.29 ± 0.01^{a}	0.98 ± 0.01^{b}
Fat	19.09 ± 0.34^{b}	21.08 ± 0.18^{a}
Fiber	0.55 ± 0.00^{a}	0.28 ± 0.04^{b}
Ash	0.73 ± 0.07^{a}	0.66 ± 0.07^{a}
Total carbohydrate	23.00 ± 1.78^{a}	22.97 ± 0.81^{a}

Values are mean ± standard deviation (n=3), while different superscripts for values in each row indicate significant differences ($P < 0.05$)

There was a significant difference ($P<0.05$) in moisture content between the selected sample (T1) (55.67 ± 0.84 g/100 g wet basis) and the control (53.70 ± 0.35 g/100 g wet basis). The higher moisture content in the developed ice cream may be attributed to the incorporation of fruit purees which have high water retention capacity. Water-binding components, such as the natural fibers in soursop and the Ceylon olive, enhance the moisture content, contributing to a smooth, creamy texture and improved palatability (Perera & Perera, 2021). No significant difference ($P>0.05$) was observed in total carbohydrate content between the developed sample (23.00 ± 1.78 g/100 g) and the control (22.97 ± 0.81 g/100 g), indicating only a negligible change of approximately 0.1%. In contrast, significant differences were observed in protein, fat, and fiber content. The developed ice cream showed higher protein content (1.29 ± 0.01 g/100 g) than the control (0.98 ± 0.01 g/100 g, $P<0.05$), likely due to the protein contribution from fruit purees, this aligns well with Ogo *et al.,* (2021) findings. Similarly, crude fiber content was significantly higher in the developed sample (0.55 ± 0.00 g/100 g) compared to the control (0.28 ± 0.04 g/100 g, $P<0.05$), which can be attributed to the natural dietary fiber present in soursop and Ceylon olive puree, contributing to improve functional attributes of the ice cream.

However, the control ice cream had slightly higher fat content (21.08 ± 0.18 g/100 g) than the developed sample (19.09 ± 0.34 g/100 g, $P<0.05$). This reduction in fat content in the fruit-incorporated ice cream may be attributed to the partial replacement of fat by fruit purees, which add moisture without compromising texture or sensory quality. Similar findings were reported by Begum *et al.* (2024) in a study on *bael* fruit, where the incorporation of fruit puree significantly reduced the fat content of ice cream. Nonetheless, ash content, representing the mineral fraction, was comparable between the two samples ($P>0.05$), indicating that the inclusion of fruit purees did not markedly alter the overall mineral content. However, some studies report that fruit addition can increase ash levels (Begum *et al.,* 2024). The higher protein and fiber content, along with balanced moisture and fat levels, suggest that the developed coconut-soursop ice cream offers enhanced nutritional value.

Evaluation of pH, total soluble solids and titratable acidity

The pH, Total Soluble Solids (TSS), and Titratable acidity of the developed ice cream sample (T1) and the control sample were measured (Table 4).

Table 4: pH, TSS, and Titratable acidity of developed ice cream sample (T1) and control sample

Treatment	pH	Titratable Acidity (%)	TSS (°Brix)
Developed ice cream (T1)	4.42 ± 0.01^{b}	0.72 ± 0.06^{a}	23.27 ± 0.75^{b}
Control sample	6.48 ± 0.02^{a}	0.33 ± 0.06^{b}	33.23 ± 0.83^{a}

Values are mean ± standard deviation (n=3), while different superscripts for values in each column indicate significant differences ($P < 0.05$)

The developed ice cream (T1) had a significantly lower pH (4.42 ± 0.01) than the control (6.48 ± 0.02), indicating higher acidity. This decrease in pH is attributed to the presence of organic acids such as malic and citric, in soursop and Ceylon olive fruit purees, which are known to lower pH in fruit-fortified non-dairy ice creams (Perera & Perera, 2021). Correspondingly, the titratable acidity was higher in the developed ice cream (0.72 ± 0.06%) compared to the control (0.33 ± 0.06%), as the fruit purees naturally increased the overall acid content. This enhanced acidity not only imparts a desirable tartness but may also contribute to improved microbial stability, a characteristic commonly observed in fruit-enriched frozen desserts (Ogo *et al.,* 2021). In contrast, the TSS measured in °Brix was significantly lower in the developed ice cream (23.27 ± 0.75 °Brix) than in the control (33.23 ± 0.83 °Brix). The reduction observed in this study is likely due

to dilution effects from the higher moisture content and the fibrous nature of the fruit purees as well as the contribution of insoluble fiber, which lowers the concentration of soluble solids. While some studies report an increase in TSS following fruit addition due to natural sugars (Rawendra and Dwi, 2020), this effect may be offset when the added fruit introduces substantial moisture and fibre, resulting in a decrease in TSS, as observed in the present study. Therefore, these results indicate that pH, titratable acidity, and TSS are significantly affected by the addition of fruit in coconut-based ice creams.

Evaluation of functional properties of the developed ice cream and control sample

Antioxidant, total phenolic, and flavonoid contents were measured for both the developed ice cream sample and the control (Table 5).

Table 5: Total phenol, antioxidant and flavonoids content of the developed ice cream sample (T1) and the control sample

Parameter	Developed ice cream (T1)	Control sample
DPPH radical scavenging activity (mg TE/ 100 g)	542.14 ± 11.00^{a}	480.48 ± 10.03^{b}
Flavonoids (mg QE/100 g)	725.00 ± 22.05^{a}	427.79 ± 12.73^{b}
Total Phenols (mg GAE/100 g)	334.33 ± 9.38^{a}	315.17 ± 1.91^{b}

TE = Trolox equivalent, QE= Quercetin equivalent, GAE= Gallic acid equivalent, values are mean ± standard deviation (n=3), different superscripts for values in each row indicate significant differences ($P < 0.05$)

According to the Table 5, the developed ice cream exhibited significantly higher levels of bioactive compounds, including antioxidant activity (542.14 ± 11.00 mg TE/100 g), flavonoid content (725.00 ± 22.05 mg QE/100 g), and total phenolic content (334.33 ± 9.38 mg GAE/100 g) compared to the control sample (480.48 ± 10.03 mg TE/100 g, 427.79 ± 12.73 mg QE/100 g, and 315.17 ± 1.91 mg GAE/100 g) respectively. These differences were statistically significant ($p < 0.05$), highlighting the strong functional impact of incorporating soursop and Ceylon olive purees into the formulation. This aligns well with the previous literature findings of fruit incorporated ice cream formulations that showed higher antioxidant activity, phenolic and flavonoid content compared to the control (Topdas *et al.,* 2017; Moolwong, Klinthong and Chuacharoen, 2023; Mauricio-Sandoval *et al.,* 2023). However, when compared to the previous study results presented by Mauricio-Sandoval *et al.,* (2023)The present study recorded higher levels of bioactive compounds. This increase is likely due to the synergistic effect of soursop and Ceylon olive, both rich in flavonoids, phenolic acids, tannins, and other bioactive compounds (Mutakin *et al.,* 2022; Mulwa, Mahungu and Muinde, 2023). Coconut, used as the base, also contributes additional antioxidants, further enhancing the functional properties of the ice cream (Karunasiri *et al.,* 2020). Therefore, the inclusion of soursop and Ceylon olive fruit purees, along with a coconut base, substantially enhanced the functional properties, making the developed ice cream significantly richer in antioxidants and bioactive compounds.

Shelf-life analysis of the developed ice cream sample and the control sample

Changes in physicochemical properties

Changes in titratable acidity

An increase in titratable acidity was observed over a month storage period in both the developed product (T1) and control samples (Figure 1). The developed product showed significantly higher acidity levels than the control throughout storage, rising from 0.72 ± 0.06% on day 1 to 1.22 ± 0.06% by day 28. In contrast, the control sample showed a slower increase, from 0.33 ± 0.06% to 0.65 ± 0.00% during the same period. The higher acidity in the developed sample may be due to the presence of soursop and Ceylon olive fruit purees, both of which are naturally rich in organic acids such as citric, lactic and malic

acids, as well as phenolic acids (Guevara *et al.,* 2019). These fruits likely contributed to greater acid development, enhancing microbial stability and extending the product's shelf life. Similar results were reported by Sanjeewa *et al.,* (2023) and Makwana *et al*., who observed progressive increases in acidity in fruit-based ice cream during storage which is consistent with the trend observed in the developed ice cream sample in the present study.

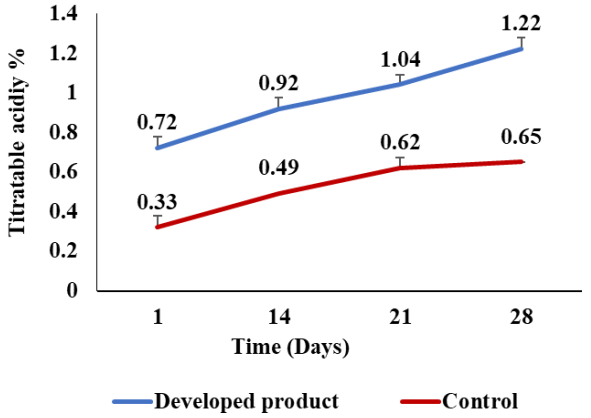

Figure 1: Changes in titratable acidity of developed product and control sample during the storage period, (n=3).

Changes in pH

The pH values of both samples decreased steadily during storage, reflecting the corresponding increase in titratable acidity (Figure 2).

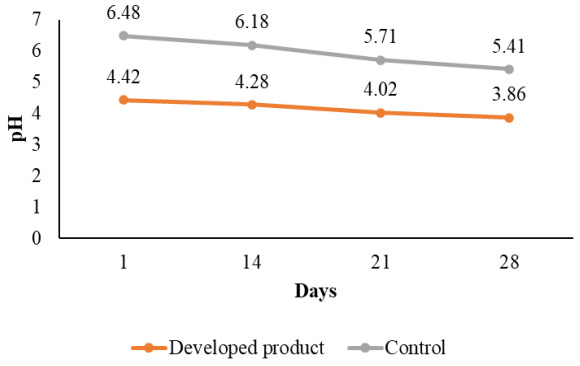

Figure 2: Changes in pH values of developed product and control sample during the storage period, (n=3)

significantly lower pH values compared to the control at each time point, declining from 4.42 ± 0.01 on day 1 to 3.86 ± 0.02 by day 28. In contrast, the control sample decreased from 6.48 ± 0.02 to 5.41 ± 0.01 during the same period. The lower initial pH of the developed sample is mainly due to the incorporation of fruit, which contributes to the development of an acidic profile. Further pH reduction may result from the breakdown of organic molecules into acidic compounds during storage. These results align with the findings reported by Begum *et al.,* (2024) and Makwana *et al.,* (2017).

Changes in total soluble solids

The TSS content increased gradually in both developed and control samples over the one-month storage period (Figure 3). In the developed ice cream, °Brix values rose from 23.27 ± 0.75 on day 1 to 26.87 ± 0.61 on day 28, while the control samples showed higher overall values, increasing from 33.23 ± 0.83 to 37.07 ± 0.75. The relatively lower TSS in the developed product can be attributed to the high moisture content of the natural fruit pulp, which dilutes the solution compared to the control, resulting in less concentrated sugar solids.

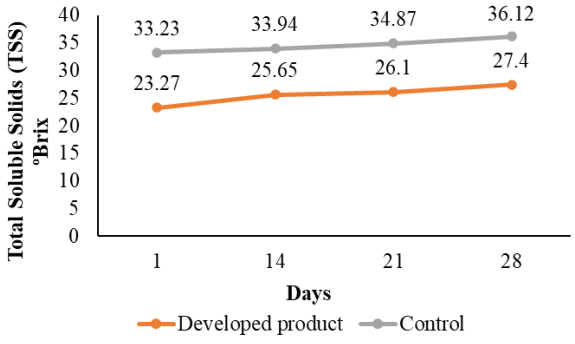

Figure 3: Changes in Total Soluble Solids values of developed product and control sample during the storage period, (n=3)

This finding contrasts with the results reported by Shelke *et al.,* (2022). However, both samples showed a gradual increase in °Brix during frozen storage, which may be due to ice crystal growth and water migration, which can concentrate soluble solids. Also, the breakdown of complex carbohydrates to simple sugar can be another reason for increasing

Brix values over time (Makwana *et al.,* 2017) These results were consistent with the previous research findings reported by Sanjeewa *et al.,* (2023). The lower TSS in the developed sample is advantageous because it aligns with health-conscious consumer preferences for reduced sugar content in ice cream.

Changes in microbiological properties

The microbial stability of the developed ice cream sample was monitored bi-weekly over a two-month storage period. Initially, on day 0, the aerobic plate count was 5×10^3 CFU/g, while presumptive coliforms, *Escherichia coli*, and *Salmonella* were not detected. *Staphylococcus aureus* and *Bacillus cereus* were found at very low levels ($<1 \times 10^1$ CFU/g). Thus, indicating that the freshly prepared product met microbiological safety standards (Table 6). On Day 14, the aerobic plate count decreased slightly to 1.86×10^3 CFU/g, while all pathogenic microorganisms remained undetectable. This reduction may be attributed to the low storage temperature, and the inhibitory effects of organic acids and bioactive compounds present in the soursop and Ceylon olive purees. On Days 28 and 42, aerobic plate counts further decreased to $<1 \times 10^3$ CFU/g, with no detection of coliforms, *E. coli*, *Salmonella*, *S. aureus*, or *B. cereus*. Notably, no preservatives were added to the formulation, yet the stable microbial profile demonstrates that the developed ice cream maintains microbial safety and quality over two months of refrigerated storage.

Table 6: Microbial count of developed ice cream during the storage period of two months, bi-weekly

Parameter	Day 0	Day 14	Day 28	Day 42
Aerobic plate count (CFU/g)	5×10^3	1.86×10^3	$<1 \times 10^3$	$<1 \times 10^3$
Presumptive Coliform count	Not detected	Not detected	Not detected	Not detected
Escherichia coli count	Not detected	Not detected	Not detected	Not detected
Staphylococcus aureus count	$<1 \times 10^1$	$<1 \times 10^1$	$<1 \times 10^1$	$<1 \times 10^1$
Salmonella species	Absent in 25g	Absent in 25g	Absent in 25g	Absent in 25g
Bacillus cereus count (CFU/g)	$<1 \times 10^1$	$<1 \times 10^1$	$<1 \times 10^1$	$<1 \times 10^1$

The low counts and absence of pathogens also reflect the combined effects of low pH, high acidity, and refrigerated conditions, which are known to inhibit microbial growth in fruit-fortified non-dairy frozen desserts. Ogo *et al.,* (2021); Mufas and Perera, (2013). Microbial counts of the developed ice cream sample remained well below the safety limits of 50,000 CFU/g as specified by the Frozen Confections Regulation. (Mufas and Perera, 2013) while confirming the safety for consumption. Moreover, these results confirm that the formulation and storage conditions are appropriate for maintaining both product quality and shelf-life.

CONCLUSION

The development of coconut-soursop-Ceylon olive ice cream has demonstrated promising results in both nutritional and functional quality. The formulation T1 (1:1 soursop: Ceylon olive fruit puree) was the preferred ice cream sample in sensory evaluation. This formulation offers a favorable balance of nutritional content. These findings suggest that T1 is a promising plant-based ice cream with enhanced nutritional and functional properties. During one month of storage, all monitored physicochemical parameters remained within acceptable limits, while microbial stability was maintained over two months, indicating the product's safety and quality under proper storage conditions (-18 ± 2 °C). These findings suggest that the developed ice cream can maintain its quality while providing functional benefits and health-promoting bioactive compounds. By evaluating the nutritional profile, sensory attributes, and storage stability of the ice cream, this study highlights its potential as a nutritious, plant-based alternative to conventional dairy ice creams, offering consumers a flavorful and functional frozen dessert. Further research is recommended to assess the long-term shelf life and optimize the formulation for broader commercial applications.

AUTHOR CONTRIBUTION

SANPS conducted the research, analyzed data, and drafted the manuscript. GSNF supervised the study, contributed to data analysis, manuscript drafting, revision, and final editing. YNA supervised the study and revised the manuscript. ABGS conceptualized the study, supervised the research, and revised the manuscript. PGSMS contributed to data analysis. TDW, and SP contributed to methodology and manuscript revision. All authors discussed the results and approved the final version of the manuscript.

REFERENCES

Akomolafe, S.F. and Ajayi, O.B. (2015) 'A comparative study on antioxidant properties, proximate and mineral compositions of the peel and pulp of ripe *Annona muricata* (L.) fruit', *International Food Research Journal*, 22 (6), pp. 2381–2388.

AOAC (2019) *Official methods of analysis of the Association of Official Analytical Chemists*. 21st edn. Washington, DC: AOAC International.

Ariyasoma, U.M.U.R. and Wathugala, D.L. (2023) 'Nutritional and therapeutic attributes of neglected and underutilized fruit crops in Sri Lanka and their potential applications in value addition', International Journal of Minor Fruits, Medicinal and Aromatic Plants, 9(2), pp. 42-51. DOI: 10.53552/ijmfmap.9.2.2023.42-51.

Association of Official Analytical Chemists (1984) *Official Methods of Analysis of the AOAC*. 14th edn. Arlington, VA, USA: AOAC.

Bajwa, U.A., Huma, N., Ehsan, B., Jabbar, K. and Khurram, A. (2003) "Effect of different concentrations of strawberry pulp on the properties of ice cream", *International Journal of Agriculture & Biology*, 5(4): 635–637.

Begum, N.J., Chandimala, U.R., Hettiarachchi, H.A.P. & Gimhani, J.A.N. (2024) 'Development of functional ice cream by incorporating bael fruit (*Aegle marmelos*) pulp and evaluation of its quality parameters', *Sri Lankan Journal of Technology*, 4(Special Issue), pp. 29–35.

Chandra, S., Khan, S., Avula, B., Lata, H., Yang, M.H., ElSohly, M.A. and Khan, I.A. (2014) 'Assessment of total phenolic and flavonoid content, antioxidant properties, and yield of aeroponically and conventionally grown leafy vegetables and fruit crops: A comparative study', Evidence-Based Complementary and Alternative Medicine, 2014, Article ID 253875. DOI: 10.1155/2014/253875.

Dahanayake, N. (2015) 'Some neglected and underutilized fruit-crops in Sri Lanka', *International Journal of Scientific and Research Publications*, 5(2), pp. 1–7.

Dulmini, A.D.T. and Perera, S.D. (2024) 'Phytochemical constituents in Kithul (Caryota urens) and its medical significance: A mini review', *OUSL Journal*, 19(1), pp. 7–26. DOI: 10.4038/ouslj.v19i1.7648.

Fernando, G.S.N., Sergeeva, N.N., Frutos, M.J., Marshall, L.J. and Boesch, C. (2022) 'Novel approach for purification of major betalains using flash chromatography and comparison of radical scavenging and antioxidant activities', *Food Chemistry*, 385, pp. 132632. ISSN 0308-8146. DOI: 10.1016/j.foodchem.2022.132632.

Fiol, C., Prado, D., Romero, C., Laburu, N., Morab, M. and Alavaa, J. I. (2016) 'Introduction of a new family of ice creams', International Journal of Gastronomy and Food Science, pp. 1–7. DOI: 10.1016/j.ijgfs.2016.12.001.

FAO (2003) *Food Energy – Methods of Analysis and Conversion Factors. Rome:* Food and Agriculture Organization of the United Nations. Available at: https://www.fao.org/3/y5022e/y5022e00.htm (Accessed: 9 October 2025).

Geburt, K., Albrecht, E.H., Pointke, M., Pawelzik, E., Gerken, M. and Traulsen, I. (2022) 'A comparative analysis of plant-based milk alternatives part 2: Environmental impacts', *Sustainability (Switzerland)*, 14(14), pp. 1–17. DOI: 10.3390/su14148424.

Góral, M., Kozłowicz, K., Pankiewicz, U.,

Góral, D., Kluza, F., and Wójtowicz, A. (2018) 'Impact of stabilizers on the freezing process, and physicochemical and organoleptic properties of coconut milk-based ice cream', *LWT*, 92, pp. 516–522. DOI: 10.1016/ j.lwt.2018.03.010.

Grand View Research (2023) Healthy Snacks Market Size, Share & Trends Report, 2030. Available at: https:// www.grandviewresearch.com/industry -analysis/healthy-snack-market (Accessed on 9 August 2025).

Guevara, M., Tejera, E., Granda-Albuja, M.G., Iturralde, G., Chisaguano-Tonato, M., Granda-Albuja, S., Jaramillo-Vivanco, T., Giampieri, F., Battino, M. and Alvarez-Suarez, J.M. (2019) 'Chemical composition and antioxidant activity of the main fruits consumed in the western coastal region of Ecuador as a source of health-promoting compounds', Antioxidants, 8(9), pp. 1–18. DOI: 10.3390/ antiox8090387.

ISO (1999) *ISO 6888-1:1999 Microbiology of food and animal feeding stuffs – Horizontal method for the enumeration of coagulase-positive staphylococci (Staphylococcus aureus and other species) –Part 1: Technique using Baird-Parker agar medium*. Geneva: International Organization for Standardization.

ISO (2004) *ISO 7932:2004 Microbiology of food and animal feeding stuffs – Horizontal method for the enumeration of presumptive Bacillus cereus – Colony-count technique at 30 °C*. Geneva: International Organization for Standardization.

ISO (2005) *ISO 7251:2005 Microbiology of food and animal feeding stuffs – Horizontal method for the detection and enumeration of presumptive Escherichia coli – Most probable number technique*. Geneva: International Organization for Standardization.

ISO (2006) *ISO 4832:2006 Microbiology of food and animal feeding stuffs – Horizontal method for the enumeration of coliforms – Colony-count technique*. Geneva: International Organization for Standardization.

ISO (2013) *ISO 4833-1:2013 Microbiology of the food chain – Horizontal method for the enumeration of microorganisms – Part 1: Colony count at 30 °C by the pour plate technique*. Geneva: International Organization for Standardization.

ISO (2017) *ISO 6579-1:2017 Microbiology of the food chain – Horizontal method for the detection, enumeration and serotyping of Salmonella – Part 1: Detection of Salmonella* spp. Geneva: International Organization for Standardization.

Jayasundera, M. and Fernando, K. (2014) 'Development and quality evaluation of coconut milk-based soft ice cream', Annals: Food Science & Technology, 15(2), pp. 227–230.

Karunasiri, A.N., Gunawardane, M., Senanayake, C.M., Jayathilaka, N. and Seneviratne, K.N. (2020) 'Antioxidant and nutritional properties of domestic and commercial coconut milk preparations', International Journal of Food Science, 2020. DOI: 10.1155/2020/3489605.

Makwana, A., Varu, D.K., Malam, V.R., Vagadia, P.S., Bhad, M. and Malam, K.V. (2017) 'Ice cream properties affected by various pulp concentrations of mango', Trends in Biosciences, 10 (16), pp. 2894–2897. Available at:https://www.researchgate.net/ publication/ 363739748_Ice_Cream_Properties_Affected_by_Various_Pulp_Concentrations_of_Mango (Accessed on 9 October 2025).

Mäkinen, O.E., Wanhalinna, V., Zannini, E. and Arendt, E.K. (2016) 'Foods for special dietary needs: Non-dairy plant-based milk substitutes and fermented dairy-type products', *Critical Reviews in Food Science and Nutrition*, 56(3), pp. 339–349. DOI: 10.1080/10408398.2012.761950

Mauricio-Sandoval, E.A., Espinoza-Espinoza, L.A., Ruiz-Flores, L.A., Valdiviezo-Marcelo, J., Moreno-Quispe, L.A.

and Cornelio-Santiago, H.P. (2023) 'Influence of the pulp of Mangifera indica and Myrciaria dubia on the bioactive and sensory properties of ice cream', *Frontiers in Sustainable Food Systems*, 7: 1126448. DOI: 10.3389/fsufs.2023.1126448.

Moolwong, J., Klinthong, W. and Chuacharoen, T. (2023) 'Physicochemical properties, antioxidant capacity, and consumer acceptability of ice cream incorporated with avocado (Persea americana Mill.) pulp', *Polish Journal of Food and Nutrition Sciences*, 73(3), pp. 289–296. DOI: 10.31883/pjfns/170938.

Mulwa, S.N., Mahungu, S.M. and Muinde, B.K. (2023) 'Effect of soursop puree and gum Arabic on the sensory properties of non-dairy coconut milk-based ice cream', *Food and Nutrition Sciences*, 14(07), pp. 670–686. DOI: 10.4236/fns.2023.147044.

Mufas, A.H.M. and Perera, O.D.A.N. (2013) 'Study on development of pitaya fruit (*Hylocereus undatus*) incorporated ice cream; an alternative solution to the pitaya cultivators in Sri Lanka', *Proceeding of the Third International Symposium*, (1), pp. 1–7.

Mutakin, M., Fauziati, R., Fadhilah, F.N., Zuhrotun, A., Amalia, R. and Hadisaputri, Y.E. (2022) 'Pharmacological activities of soursop (*Annona muricata* Lin.)', *Molecules*, 27(4), pp. 1–17. DOI: 10.3390/molecules27041201.

Nakandalage, N. and Anuruddi, H.I.G.K. (2023) 'Underutilized crops as a resource to combat the food, nutrient, and economic security in Sri Lanka', *Journal of Dry Zone Agriculture*, 9(1), pp. 81–106. DOI: 10.4038/jdza.v9i1.70.

Ogo, O., Emmanuella, B., Esienanwan, E. and Daniel, E. (2021) 'Nutritional and sensory evaluation of novel ice cream products formulated from Kunu-Zaki fortified with fruit pulp', *Food and Nutrition Sciences*, 12(05), pp. 439–451. DOI: 10.4236/fns.2021.125034.

Perera, K.D.S.S. and Perera, O.D.A.N. (2021) 'Development of coconut milk-based spicy ice cream as a nondairy alternative with desired physicochemical and sensory attributes', *International Journal of Food Science*, 2021. DOI: 10.1155/2021/6661193.

Patil, A. (2024) 'Global vegan ice-cream market: Global industry analysis and lucrative growth opportunities', *ResearchGate*, November. DOI: 10.13140/RG.2.2.30007.94887.

Perera, S., Silva, A.B.G., Amarathunga, Y., De Silva, S., Jayatissa, R., Gamage, A., Merah, O. and Madhujith, T. (2022) 'Nutritional composition and antioxidant activity of selected underutilized fruits grown in Sri Lanka', *Agronomy*, 12(5). DOI: 10.3390/agronomy12051073.

Pinandoyo, D.B., Masnar, A., Haryati, R.T. and Badgujar, S. (2021) 'Sensory characteristic of new formulated Bir Pletok ice cream', *Canrea Journal: Food Technology, Nutritions, and Culinary Journal*, 4(1), pp. 59–67. DOI: 10.20956/canrea.v4i1.395.

Poore, J. and Nemecek, T. (2018) 'Reducing food's environmental impacts through producers and consumers', *Science*, 360(6392), pp. 987–992. DOI: 10.1126/science.aaq0216.

Ranawake, A.L., (2021). The underutilized resources in the lowland wet zone forests of Sri Lanka and untapped indigenous knowledge of peripheral households. *Journal of the University of Ruhuna*, 9(2), pp. 47–71, DOI: http://dx.doi.org/10.4038/jur.v9i2.7997

Rawendra, R.D.S. and Dwi, G.N. (2020) 'Enrichment of soft ice cream with different fibrous fruit puree: Physicochemical, textural characteristics and sensory properties', *IOP Conference Series: Earth and Environmental Science*, 426(1). DOI: 10.1088/1755-1315/426/1/012178.

Rehal, J., Thapa, A. and Kaushal, P. (2025) Benefits and challenges in plant-based milk alternatives', *Journal of Innovative Agriculture* [Preprint], June. DOI: 10.37446/jinagri/ra/12.2.2025.1-11.

Roshana, M.R., Banu, M.J.A. and Pre-

makumar, K. (2025) 'Development of coconut milk-based ice cream incorporated with soursop (*Annona muricata* L.) fruit puree', *Proceedings of ICTRI 2025*, Faculty of Technology, Eastern University, Sri Lanka, February.

Saha, S., Do, T., Maycock, J., Wood, S. and Boesch, C. (2023) 'Antibiofilm efficacies of flavonoid-rich sweet orange waste extract against dual-species biofilms', *Pathogens*, 12(5), p. 657. DOI: 10.3390/pathogens12050657.

Sanjeewa, P., Mylvaganam, P., Liyinthan, V. and Janaranjana, T.N. (2023) 'Evaluation of physicochemical and sensory properties of ice cream incorporating processed amla', *European Journal of Agriculture and Food Sciences*, 5(1), pp. 40–45. DOI: 10.24018/ejfood.2023.5.1.600.

Shelke, G.N., Kad, V.P., Yenge, G.B. and Kakade, S.R. (2022) 'Development of antioxidant rich ice cream using spray dried Jamun juice powder', *Journal of Agriculture Research and Technology*, 47(2), pp. 233–238. DOI: 10.56228/jart.2022.47220.

Sri Lanka Standards Institution (2011) *SLS 516: Part 5:2011 Microbiology of food and animal feeding stuffs – Horizontal method for the detection of Salmonella* spp. Colombo: SLSI.

Sri Lanka Standards Institution (2013a) *SLS 516: Part 1:2013 Microbiology of food and animal feeding stuffs – Horizontal method for the enumeration of microorganisms – Colony count technique at 30 °C*. Colombo: SLSI.

Sri Lanka Standards Institution (2013b) *SLS 516: Part 8:2013 Microbiology of food and animal feeding stuffs – Horizontal method for the enumeration of presumptive Bacillus cereus – Colony-count technique at 30 °C*. Colombo: SLSI.

Sri Lanka Standards Institution (2013c) *SLS 516: Part 12:2013 Microbiology of food and animal feeding stuffs – Horizontal method for the detection and enumeration of presumptive Escherichia coli – Most probable number technique*. Colombo: SLSI.

Sri Lanka Standards Institution (2013d) *SLS 614:2013 Microbiology of food and animal feeding stuffs – Horizontal method for the enumeration of coliforms – Colony-count technique*. Colombo: SLSI.

Topdaş, E.F., Çakmakçı, S. and Çakıroğlu, K. (2017) 'The antioxidant activity, vitamin C contents, physical, chemical and sensory properties of ice cream supplemented with Cornelian cherry (*Cornus mas* L.) paste', *Kafkas Üniversitesi Veteriner Fakültesi Dergisi*, 23(5), pp. 691–697. DOI: 10.9775/kvfd.2016.17298.

Weeraratne, P. and Ekanayake, S. (2022) Kithul (Caryota urens) treacle: A healthy natural sweetener?', *Ceylon Medical Journal*, 67(1), p. 11. DOI: 10.4038/cmj.v67i1.9553.