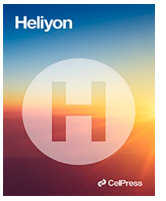
Heliyon 10 (2024) e40711

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon



Research article

Effect of essential oils as vitamin C preservatives and chia seed (*Salvia hispanica*) in the fortification of pineapple jam

Tanima Jarin [a,*], Md Nazrul Islam [a], Shormin Choudhury [a], Md Rabiul Islam [b], Reana Raen [c], Redwanul Islam [d], Sika Mustaki [a]

[a] *Department of Horticulture, Sher-e-Bangla Agricultural University, Dhaka, Bangladesh*
[b] *Department of Electrical and Electronic Engineering, Jashore University of Science & Technology, Bangladesh*
[c] *Department of Biomedical Engineering, Chittagong University of Engineering & Technology, Bangladesh*
[d] *Department of Biomedical Engineering, Khulna University of Engineering & Technology, Bangladesh*

ARTICLE INFO

Keywords:
Chia seed
Cinnamon essential oil
Lemongrass essential oil
Pineapple Jam
Vitamin C

ABSTRACT

The present investigation "Effect of essential oils and chia seed (*Salvia hispanica*) in fortification of pineapple jam." was conducted during the year 2022–2023 at the Post harvest laboratory of Horticulture Department, Sher-e-Bangla Agricultural University, Dhaka. The study investigated the effects of essential oil and chia seeds on the quality of pineapple jam. In this research, pineapple jam samples were prepared with varying essential oil such as Cinnamon essential oil and Lemongrass essential oil at range of 1000 ppm. The addition of essential oil significantly impacted the flavour profile of the jam, enhancing the fruity notes and providing a pleasant aroma in sustainable and eco-friendly way. Moreover, it exhibited antimicrobial properties, extending the shelf life of the jam. Chia seeds were incorporated into the jam at different levels (6.25 %, 12.5 %, 25 % and 50 %) to assess their influence on texture and nutritional content. The results indicated that chia seeds contributed to a thicker consistency and increased protein content, making the jam a potential source of dietary protein. The maximum pH was found to be 4.90 from treatment (C_4E_0 = 50 % chia and no Essential oil). The lowest pH was recorded at 3.63 for C_oE_2 = No chia seed and 1000 ppm Lemongrass Essential oil). The investigation shows that lemongrass essential oil (E_2) showed the best result in vitamin C retention. In case of chia seed 50 % (C_4) treatment showed the best protein content. Additionally, the seeds added a subtle crunch and nutty undertone to the product. From the research it can be concluded that the treatment (C_4E_2 = 50 % chia seed and 1000 ppm Lemongrass Essential oil) showed the best result in case of vitamin C retention and protein incorporation. But considering spread ability and appearance (C_3E_2 = 25 % chia seed and 1000 ppm Lemongrass Essential oil) can be considered as best treatment for consumers. This research is motivated by the need to develop healthier, nutrient-dense pineapple jam using natural preservatives and fortifying agents. By exploring the combined effects of essential oils and chia seeds in preserving vitamin C and improving the jam's overall nutritional value, this study aims to meet the increasing demand for functional foods that prioritize both health and taste. The outcomes could offer valuable insights into natural preservation techniques and fortification strategies, potentially contributing to more sustainable and consumer-friendly food products in the market.

* Corresponding author. Department of Horticulture, Sher-e-Bangla Agricultural University, Dhaka, Bangladesh.
E-mail address: tanimajarinjyoti@gmail.com (T. Jarin).

https://doi.org/10.1016/j.heliyon.2024.e40711
Received 24 June 2024; Received in revised form 22 November 2024; Accepted 25 November 2024
Available online 29 November 2024

1. Introduction

Pineapple, also known as (*Ananas comosus*) is a delightful tropical fruit that is high in nutrients, vitamins and minerals [1]. Being delicious and fragrant fruit, it is widely cultivated in the world. Bangladesh has a great probability of pineapple cultivation [2]. According to Bangladesh Bureau of Statistics (BBS) report, most of the pineapples are cultivated in Dhaka, Sylhet, Chittagong Hill Tract and Tangail area [3]. Dhaka region is the highest cultivable land in Bangladesh [4]. After fulfilling the local demand, there has found a surplus quantity of pineapple. The cultivators are usually forced to either sell the excess quantity at a low price or destroy the fruits. Every year a large amount of pineapple gets damaged due to lack of proper preservation and processing [5]. As a result, farmers are losing hope and shifting farming. This damage can be minimized by making of value-added products of pineapple and can be served whole year. By making jam these can be preserved for years by using essential oils as a plant source. In contrast, when fruits are processed to jam, the percentage of nutritional value drop significantly [6]. Moreover, jams normally have lower vitamin C content compared to their fresh fruits counterpart [7,8]. This is due to the result of heat to which they are exposed during processing. A solution of this problem is to fortify jam with nutrient dense food products such as chia seeds. These are unprocessed, ready to eat and the whole grain contains up to 39 % oil which has the highest known content of alfa linolenic acid [9]. Jam can be added with value by using chia seed. Essential oil comes from plant source. It also adds flavor and aroma [10]. These are volatile compounds of the plants that are responsible for aroma, taste, and even the antimicrobial nature of the plants. Many essential oils have been reported having radical-scavenging ability and thus reducing oxidation, which can cause oxidative deterioration, including loss of vitamin C [11]. Combination of essential oils can work synergistically and more effective than single essential oils [12]. So essential oils can be added to pineapple jam to increase the shelf life of jam. While many studies have focused on the fortification of common jams like strawberry, apple or black berry [13–16]. But the research using pineapple jam provides a fresh perspective. Other researchers have either investigated on chia seed or essential oil separately but failed to work in combination [3,9,10,12]. Combination of these both chia and essential oil has not been done before. The study explores the unique combination of essential oils as natural preservatives alongside chia seed in fortification [17,18]. This dual approach is novel in enhancing both the nutritional profile and shelf life of pineapple jam. The research provides insights into how this superfood can be integrated into traditional fruit preserves. Pineapple's unique composition, combined with chia seeds and essential oils, offers an underexplored area of research [19–21]. The processed pineapple jam might be popular and nutritious source for future industrialization and can improve socio economic condition of farmers. The comparison of the present work with related works in respect of different factor has been included in Table 1.

This research stands out for its combined exploration of essential oils and chia seeds in fortifying pineapple jam, bringing together concepts of natural preservation, nutrient fortification and novel ingredient incorporation. Pineapple's unique composition, combined with chia seed and essential oils, offers an underexplored area of research. The focus on pineapple jam, essential oils as vitamin C preservatives and the functional role of chia seeds can be contrasted against studies on different fruits, preservatives and fortification strategies to draw more nuanced insights on efficacy, sensory qualities and consumer acceptability. The present investigation was therefore, carried out with a view to achieving the following objectives.

2. Objectives

i. To add nutritional value in pineapple jam with chia seed and evaluate its sensory characteristics along with nutritional benefits.
ii. To evaluate the effect of essential oil and chia seed on storability and quality of jam.

3. Materials and methodology

3.1. Work flow

The work flow is given in Fig. 1.

Table 1
Comparison of the present work with related works.

Related work					Present work			
Reference no.	Parameter	Methods of analysis	Findings		Parameter	Methods of analysis	Findings	
[22]	Loss of Vitamin C %	Using 2,6 dichlorophenol indophenol titration method	Highest value 35 % loss	Lowest value 15 % loss of vit C	Vitamin C content mg/100 g	Using 2,6 dichlorophenol indophenol titration method	Highest value 4.99 mg/100 g	Lowest value 0.96 mg/100 g
[23]	Protein content %	Kjeldahl method	4.65 %	0.53 %	Protein content (g/L)	Lowry Protein Assay	8.83 g/L	0.95 g/L
[24]	Bacterial content (CFU/mL)	Agar diffusion using CGA growth media	10^8 CFU/mL	1.03×10^2 CFU/mL	Bacterial content (CFU/mL)	Bacterial count using NA growth media	780 CFU/mL	84 CFU/mL
[25]	Moisture %	Oven dry method	43.22 %	24.79 %	Moisture %	Oven dry method	33.34 %	11.47 %
[23]	pH	pH meter	3.7	3.2	pH	Using pH meter	4.90	3.63

3.1.1. Experimental design

The experiment was conducted with completely randomized design (CRD) in Postharvest laboratory at Sher-e-B Bangla Agricultural University, Sher-e-Bangla Nagar, Dhaka, Bangladesh.

3.1.2. Experimental materials and experimental site

The experiment was carried out in post-harvest laboratory maintaining proper hygiene and cleanliness. Pineapple (Giant kew) has been obtained from Karwan bazar, Tejgaon, Dhaka, Bangladesh. Proper procedure has been followed to prepare jam. Essential oils, Sugar, Jars and Dish for jam preparation was collected.

3.1.3. Treatments

The experiment consisted of two factors as follows:

Two factors contributed to the experiment has been included in the following Table 2.

The treatment combination was 15 and with 3 replications the total jar number was 45.

3.1.4. Data collection

Various physical and chemical characteristics and quality parameters were assessed.

3.1.5. Physical characters

Color, Texture, Flavor, Taste, Spread ability, General acceptability.

3.1.6. Chemical characteristics

PH of jam, Brix, Titratable acidity, Reducing sugar, Protein content, Vitamin C content, Moisture content.

Fig. 1 shows the block diagram for the preparation of pineapple jam. At first fresh pineapples were collected and peeled off. Then these were washed and cut into pieces removing the pineapple eye. After that slicing and blending was done. Then the pulps were moved for boiling after addition of sugar. The sugar was added same as the amount of pulps. After stirring and boiling jam preparation was finished, when a sticky consistency appeared [26]. After that chia seed and essential oil was added. The prepared jam was cooled and poured in jars by mixing with respective treatments.

3.2. Sample collection

The investigation was conducted during the year 2022–2023 at the Post harvest laboratory of Horticulture Department, Sher-e-Bangla Agricultural University, Dhaka, Bangladesh. In this research, pineapple jam samples were prepared with varying essential oils and chia seed. Two essential oils, Cinnamon essential oil and Lemon grass essential oil was added. C_0=No chia seed, $C_1 = 6.25$ % chia seed, $C_2 = 12.5$ % chia seed, $C_3 = 25$ % chia seed, $C_4 = 50$ % chia seed, E_0 = No Essential Oil, $E_1 = 1000$ ppm Cinnamon Essential Oil, $E_2 = 1000$ ppm Lemon grass Essential Oil. Essential oils and Chia seeds were mixed with jam and samples were collected. The experiment was done in 15 combination and with 3 replications 45 samples were collected. Each sample was filled with 200 mL jam from different treatment.

3.3. Determination of pH and Brix of pineapple jam

The pH of pineapple jam was determined by using pH meter in the laboratory. For determining pH each sample was diluted with distilled water in 1:2 ratio. On the other hand the total soluble solids of pineapple jam samples was obtained by using a refractometer

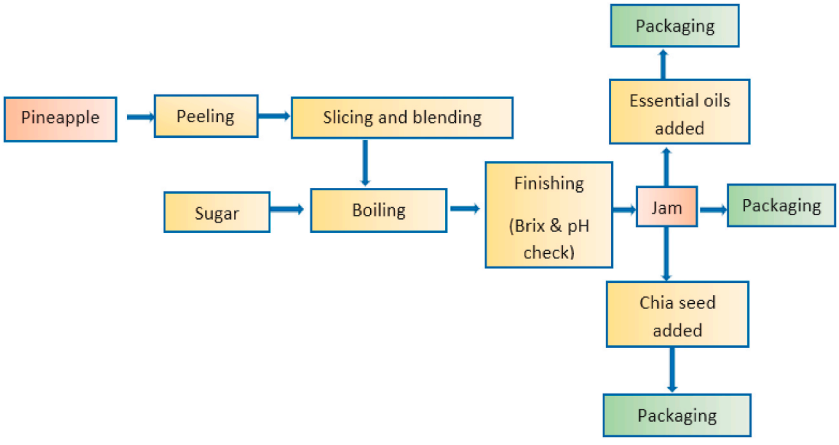


Fig. 1. Process for preparation of pineapple Jam.

Table 2
Factors contributed to the present work.

Factor A: Different level of chia seed	Factor B: Different level of Essential oil
C_0: No chia seed	E_0: Control
C_1: 6.25 % chia seed	E_1: 1000 ppm Cinnamon essential oil
C_2: 12.5 % chia seed	E_2: 1000 ppm Lemongrass essential oil
C_3: 25 % chia seed	
C_4: 50 % chia seed	

[26,27]. Prior measuring, each sample was diluted by taking 5 mL sample and 10 mL distilled water.

3.4. Determination of titratable acidity

For measuring Titratable acidity 5 gm of sample were taken and 10 mL distilled water was added. After filtering 60 mL volume was made with water. Then (10 mL) volume was made and 2/3 drops phenolphthalein indicator was added. Titration was done obtaining pink color with NaOH (0.1N).

3.5. Determination of reducing sugar

Four solution, solution A, solution B, solution C and solution D was prepared. Solution A-(1 mL NaOH in 100 mL distilled water). Solution B-(2 gm DNS and 400 gm crystal phenol added in solution A). Solution C-(50 mg Na_2SO_3 added in 100 mL distilled water). Solution D-(40 % Rochelle salt). At first 0.1 mL sample and 0.1 mL distilled water was added in 3 mL of solution D. Then the contents were placed in water bath for 15 min. The test tubes were cooled and 1 mL of D solution was added. After that 1 mL of solution C was added. Then spectrometer reading was taken at 575 nm.

3.6. Determination of vitamin C

For determining vitamin C, 5 gm sample was taken and 15 mL oxalic acid was added. After filtering volume was made 100 mL by addition of oxalic acid. Then 3 beakers of 10 mL was taken and titrated against 2, 6-dichloroindophenol until pink color was obtained.

3.7. Determination of protein content

Protein concentration of pineapple jam was determined by Lowry method. Chemicals such as BSA (Bovine Serum Albumin), Stock solution (1000 micro g/mL), and distilled water was taken. Then three reagents were prepared where reagent A contained 2 % Na_2CO_3 in 0.1 % NaOH, reagent B contained 0.1 % $CuSO_4$ in 1 % Na–K Tartrate, reagent C contained 50 mL reagent A and 1 mL reagent B. Another reagent Folin and ciocalteu's phenol reagent 1:1 was prepared.

3.8. Reagent making

1000 micro g/mL BSA stock solution was prepared by adding 100 mg BSA in 100 mL distilled water. Reagent A was prepared by taking 0.1 gm NaOH in 100 mL distilled water. After that 2 gm Na_2CO_3 was added in that solution. Reagent B was prepared by adding 1 g Na-K tartrate in 100 mL distilled water. After that 0.1 g $CuSO_4$ was added in that solution. Reagent C was prepared by mixing 50 mL reagent A and 1 mL reagent B. Standard curve was prepared to know the concentration of stock solution. Test sample reading was obtained by following certain protocol such as at first test sample was taken and 4 mL reagent C was added. Then it was incubated for 10 min and FC reagent 0.4 mL was added and incubated for 15 min at room temperature. Then absorbance reading was obtained at 660 nm. The unknown concentration was obtained by following formula (1) [28].

$$\text{Unknown concentration} = \frac{\textit{test sample O.D (absorbance)}}{\textit{BSA slope}} \quad (1)$$

Here, test sample O.D (absorbance) = 580 μg/mL,
BSA slope = 0.9936.

3.9. Determination of moisture content

Moisture content was determined by following steps.

Step 1: The clear glass petri dish was placed in oven keeping the lid opened and separated at 105^o for 20 min. Then these were dried to remove the moisture from the plate. After drying the plates were placed to desiccator for cooling.
Step 2: The petri plates were placed on the balance machine and the weight of the petri plates were noted. 5 g of each sample was taken in the petri plate and the weight of the sample was noted and the sample was kept for drying.

Step 3: The petri dish was put in the hot air oven and the door was closed. The temperature was set at 135^{o} and dried for 2 h. After 2 h the petri dishes were taken out. Then the petri dishes were cooled in desiccator.
Step 4: The final weight of the petri dish containing the dried sample was taken. The petri dish with sample was placed in the machine. The final weight was taken. Moisture was calculated from equation (2) [29].
Step 5: Calculation was done by following formula:

Weight of the dish = w_1
Weight of the sample = w_s
Weight of the dish after drying = w_2

$$\text{Moisture \%} = \{w_s\text{-}(w_2\text{-}w_1)/w_s\}*100 \quad (2)$$

3.10. Determination of bacteria

The amount of bacteria was count by following bacterial count method. For bacterial count NA (Nutrient Agar) growth media was used. The Petri dish was divided in four zone and highest growth part was count and multiplied for total bacterial count. Bacterial count CFU/mL was determined by following formula (3). Fig. 2 shows the bacterial count from sample. The petridishes were filled with sample and NA growth media. After following methods colonies were count and Colony Forming Unit (CFU) was calculated using formula (3) [30].

$$\text{CFU/mL} = (\text{Number of colonies}*\text{Dilution factor})/\text{ Volume of culture plate} \quad (3)$$

Here, Dilution factor = 6,
Volume of culture plate = 1 mL.

3.11. Statistical analysis

The research data for various characteristics of the study's subjects were subjected to statistical analysis using Statistics 10 software to determine the significance of the variations between chia seeds and essential oil. The average values for all the observed traits were calculated, and an analysis of variance was conducted using the 'F' (variance ratio) test. To assess the disparities between the treatments, the Least Significant Difference (LSD) test was employed at a significance level of 0.05 %, following the methodology outlined by Ref. [31].

4. Results

The study aimed to investigate the multifaceted effects of essential oil and chia seeds on the quality attributes of pineapple jam, focusing on protein content, pH, Brix level, vitamin C concentration, microbial activity, and moisture content. Pineapple jam is a popular and widely consumed fruit preserve. However, enhancing its nutritional profile and extending its shelf life are ongoing challenges in the food industry. Essential oils, known for their flavor-enhancing and antimicrobial properties, and chia seeds, rich in nutritional benefits, were selected as potential additives for this research.

To assess the effects of these additives, pineapple jam samples were prepared and the following key attributes were evaluated.

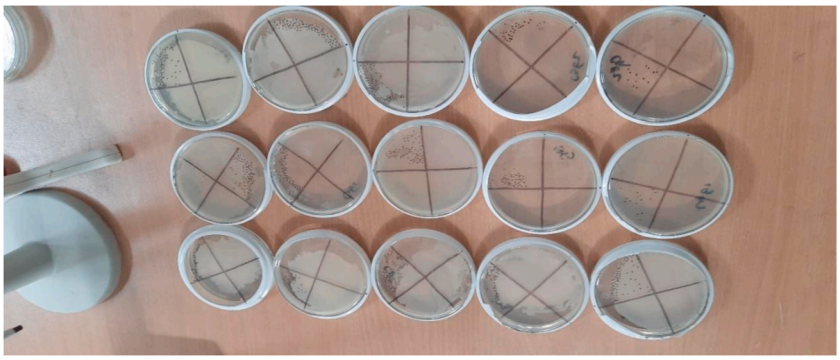


Fig. 2. Bacterial count from sample.

4.1. pH level

The pH of the pineapple jam was measured to determine its acidity. From Table 3 the results showed that the inclusion of essential oil did not significantly alter the pH, indicating that it had minimal impact on the acidity of the product. The maximum pH was recorded at 4.90 from treatment (C_4E_0 = 50 % chia and no Essential oil). The lowest pH was recorded at 3.63 for (C_oE_2 = No chia seed and 1000 ppm Lemongrass Essential oil).

4.2. Brix level

Brix level is an important indicator of the sugar content in fruit products. From Table 3 the study found that the Brix level in the pineapple jam remained relatively stable with the addition of essential oil. However, the inclusion of chia seeds led to a slight increase in Brix level. The maximum Brix recorded was 72.50 for 90 days at E_1 and E_2. The minimum value of Brix was 69.30 for 30 days at E_0.

4.3. Titratable acidity (TA)

The maximum TA recorded was 0.47 from treatment (C_0E_2 = No chia and 1000 ppm Lemongrass Essential oil.) at 90 days which was shown in Table 3. The lowest TA recorded was 0.06 for treatment (C_4E_1 = 50 % chia seed and 1000 ppm Cinnamon Essential oil) at 30 days.

4.4. Reducing sugar

The maximum reducing sugar recorded was 37 from treatment (C_0E_1 = No chia and 1000 ppm Cinnamon Essential oil) at 90 days. The lowest reducing sugar recorded was 9.43 for treatment C_0E_1 = No chia seed and 1000 ppm Cinnamon Essential oil) at 30 days.

Effect of chia seed and essential oil on titratable acidity and reducing sugar of pineapple jam and the effect of chia seed and essential oil on vitamin C and protein of pineapple jam had been shown in Table 4 and Table 5 respectively. Also the effect of chia seed and essential oil on moisture and bacteria of pineapple jam and the effect of chia seed and essential oil on colour of pineapple jam had been

Table 3
Effect of chia seed and essential oil on pH and Brix level of pineapple jam after preparation.

Treatment	PH			Brix		
	30 Days	60 Days	90 Days	30 Days	60 Days	90 Days
A. Chia Seed						
C_0	3.9267c	4.00d	4.10d	68.0d	69.00e	70.33d
C_1	3.8367c	4.26c	4.40c	69.66c	70.16d	71.33c
C_2	4.3122b	4.38bc	4.56bc	70.33b	71.00c	71.50c
C_3	4.3667b	4.43b	4.60b	69.50c	71.83b	72.16b
C_4	4.5767a	4.71a	4.85a	72.16a	73.33a	73.83a
CV%	2.53	3.06	4.26	0.70	0.69	0.82
$LSD_{0.05}$	0.1026	0.1287	0.1853	0.4759	0.4712	0.5654
B.Essential oil						
E_0	4.10b	4.23b	4.40b	69.40b	70.00c	70.50b
E_1	4.42a	4.47a	4.59a	69.30b	71.80a	72.50a
E_2	4.08b	4.38a	4.52 ab	71.10a	71.40b	72.50a
CV%	2.53	3.06	4.26	0.70	0.69	0.82
$LSD_{0.05}$	0.0795	0.0997	0.1435	0.3686	0.3650	0.4380
C. Combination						
C_0 E_0	3.65e	3.90i	4.00f	67.00f	68.00f	68.50g
C_0E_1	4.50b	4.00hi	4.10ef	68.00e	69.00e	69.50f
C_0E_2	3.63e	4.10ghi	4.20def	69.00d	70.00cd	73.00b
C_1 E_0	3.66e	4.10ghi	4.20def	69.00d	69.50de	70.00ef
C_1 E_1	4.10d	4.50cde	4.60abc	70.00c	70.50c	73.00b
C_1 E_2	3.75e	4.20fgh	4.40cde	70.00c	70.50c	71.00cd
C_2 E_0	4.40bc	4.30efg	4.50bcd	70.00c	70.00cd	70.50de
C_2 E_1	4.30c	4.50cde	4.70abc	68.00e	74.00a	74.50a
C_2 E_2	4.23cd	4.35def	4.50bcd	73.00a	69.00e	69.50f
C_3 E_0	4.30c	4.30efg	4.50bcd	68.00e	70.00cd	70.50de
C_3 E_1	4.50b	4.60bc	4.70abc	69.00d	72.00b	71.50c
C_3 E_2	4.30c	4.40cdef	4.60abc	71.50b	73.50a	74.50a
C_4 E_0	4.50b	4.55bcd	4.80 ab	73.00a	72.50b	73.00b
C_4 E_1	4.70a	4.75 ab	4.85a	71.50b	73.50a	74.00a
C_4 E_2	4.53 ab	4.85a	4.90a	72.00b	74.00a	74.50a
CV%	2.53	3.06	4.26	0.70	0.69	0.82
$LSD_{0.05}$	0.1777	0.2229	0.3210	0.8242	0.8161	0.9793

N.B.: C_0=No chia seed, C_1 = 6.25 % chia seed, C_2 = 12.5 % chia seed, C_3 = 25 % chia seed, C_4 = 50 % chia seed, E_0 = No Essential Oil, E_1 = 1000 ppm Cinnamon Essential Oil, E_2 = 1000 ppm Lemon grass Essential Oil.

shown in Table 6 and Table 7 respectively.

4.5. Vitamin C concentration

Vitamin C is a vital nutrient in fruits and plays a crucial role in human nutrition. The study assessed the impact of essential oil and chia seeds on vitamin C concentration in the jam. In 30 days, in case of E_0 (No essential oil) the amount of vitamin C in jam was 2.42 mg/100g. For E_1 (1000 ppm Cinnamon Essential oil) vitamin C content was 4.3 mg/100g and for E_2 (1000 ppm Lemongrass Essential oi) vitamin C content was 4.99 mg/100g (Table: 4). Fig. 3 indicates that addition of essential oil increased vitamin C content in pineapple jam. Both Cinnamon and Lemongrass essential oil were found to be more effective than control and Lemongrass oil showed the best result.

4.6. Protein content

From Table 5 we found that the addition of chia seeds significantly increased the protein content of the pineapple jam. The maximum protein content recorded was 8.82 g/L incase of 30 days from the treatment C_4E_2 (50 % chia seed and 1000 ppm Lemongrass Essential oil). The lowest amount of protein content recorded was (0.62 g/L) for the sample C_0E_0 (C0 = 0 % chia seed and no Essential oil) in 90 days. The graphical presentation from Fig. 4 showed the increase in protein content by adding chia seed. The treatment containing more chia seed was found to have more protein content. As chia seeds are a good source of plant-based protein, their incorporation contributed to the overall protein content, making the jam a potential protein-rich snack option. The graphical presentation showed increase in protein content by adding chia seed.

4.7. Moisture content

Moisture content is a crucial factor in the texture and stability of fruit preserves. The research showed that the inclusion of chia seeds led to a slight increase in moisture content, potentially influencing the product's texture and overall sensory attributes. The maximum moisture content was recorded 33.34 % from treatment (C_0= No chia seed). The lowest moisture recorded was 11.47 % for

Table 4
Effect of chia seed and essential oil on Titratable Acidity and Reducing Sugar of pineapple jam.

Treatment	Titratable Acidity			Reducing Sugar		
	30 Days	60 Days	90 Days	30 Days	60 Days	90 Days
A. Chia Seed						
C_0	0.28a	0.37a	0.43a	12.63c	30.53a	34.10a
C_1	0.18b	0.27b	0.30b	15.59a	29.20b	32.46b
C_2	0.14c	0.18c	0.19c	13.06b	28.59c	32.40b
C_3	0.10d	0.13d	0.14d	11.00e	23.39d	26.90c
C_4	0.06e	0.07e	0.08e	11.60d	22.61e	26.24d
CV%	2.00	1.53	0.26	2.35	1.32	1.16
$LSD_{0.05}$	0.003	0.004	0.006	0.2901	0.3419	0.3419
B. Essential oil						
E_0	0.13c	0.18c	0.21c	12.04c	26.62b	30.07b
E_1	0.16b	0.20b	0.21b	12.84b	28.00a	31.67a
E_2	0.17a	0.24a	0.26a	13.45a	25.97c	29.53c
CV%	2.00	1.53	0.26	2.35	1.32	1.16
$LSD_{0.05}$	0.002	0.002	0.004	0.2247	0.2648	0.2648
C. Combination						
C_0 E_0	0.24c	0.32c	0.40c	11.79f	31.56b	35.37b
C_0E_1	0.29b	0.37b	0.41b	13.78c	33.19a	37.00a
C_0E_2	0.31a	0.44a	0.47a	12.33e	26.84f	29.92f
C_1 E_0	0.14g	0.24e	0.25f	14.87b	28.29e	31.19e
C_1 E_1	0.19e	0.25d	0.26e	16.14a	30.65c	33.92c
C_1 E_2	0.21d	0.32c	0.38d	15.78a	28.65e	32.28d
C_2 E_0	0.12h	0.17g	0.20g	12.87d	30.11cd	33.92c
C_2 E_1	0.14g	0.19f	0.19i	13.96c	29.56d	33.55c
C_2 E_2	0.17f	0.19f	0.19h	12.33e	26.12g	29.74f
C_3 E_0	0.12i	0.21i	0.12l	10.52gh	21.58j	25.21i
C_3 E_1	0.12h	0.12i	0.13k	9.43i	23.39i	27.02h
C_3 E_2	0.06k	0.15h	0.17j	13.06d	25.21h	28.47g
C_4 E_0	0.03l	0.04l	0.07o	10.15h	21.58j	24.66i
C_4 E_1	0.06k	0.07k	0.08n	10.88g	23.21i	26.84h
C_4 E_2	0.09j	0.09j	0.09m	13.78c	23.03i	27.20h
CV%	2.00	1.53	0.26	2.35	1.32	1.16
$LSD_{0.05}$	0.005	0.005	0.009	0.5025	0.5922	0.5922

N.B.: C_0=No chia seed, C_1 = 6.25 % chia seed, C_2 = 12.5 % chia seed, C_3 = 25 % chia seed, C_4 = 50 % chia seed, E_0 = No Essential Oil, E_1 = 1000 ppm Cinnamon Essential Oil, E_2 = 1000 ppm Lemon grass Essential Oil.

Table 5
Effect of chia seed and essential oil on Vitamin C and Protein of pineapple jam.

Treatment	Vitamin C (mg/100 g)			Protein(gm/L)		
	30 Days	60 Days	90 Days	30 Days	60 Days	90 Days
A. Chia Seed						
C_0	3.84b	2.88d	2.62c	0.96e	0.83e	0.71e
C_1	4.22a	3.83b	3.26a	1.65d	1.71d	1.46d
C_2	4.16a	4.16a	3.26a	2.41c	2.13c	1.89c
C_3	3.39c	3.52c	2.88b	4.77b	4.23b	3.69b
C_4	3.77b	3.52c	2.88b	8.83a	7.73a	3.88a
CV%	2.59	2.42	0.62	5.60	0.16	0.22
$LSD_{0.05}$	0.0906	0.0898	0.0177	0.20	0.005	0.006
B. Essential oil						
E_0	2.42c	1.92c	0.96c	3.71a	3.19c	2.67c
E_1	4.30b	3.83b	3.68b	3.67a	3.37b	3.04b
E_2	4.91a	4.99a	4.30a	3.78a	3.42a	3.07a
CV%	2.59	2.42	0.62	5.60	0.16	0.22
$LSD_{0.05}$	0.0702	0.0695	0.0137	0.16	0.004	0.005
C. Combination						
C_0 E_0	3.28e	1.92e	0.96d	0.95f	0.79o	0.64m
C_0E_1	3.84d	2.88d	3.07c	0.96f	0.84n	0.73l
C_0E_2	4.42c	3.84c	3.84b	0.96f	0.85m	0.76k
C_1 E_0	1.92g	1.92e	0.96d	1.65de	1.65l	1.31j
C_1 E_1	4.99b	3.82c	3.84b	1.34e	1.74j	1.53i
C_1 E_2	5.76a	5.76a	4.99a	1.95d	1.73k	1.57h
C_2 E_0	3.07f	1.92e	0.96d	2.41c	2.00i	1.70g
C_2 E_1	4.42c	4.80b	3.84b	2.42c	2.16h	1.98f
C_2 E_2	4.99b	5.76a	4.99a	2.41c	2.21g	1.99f
C_3 E_0	1.92g	1.92e	0.96d	4.76b	4.06f	3.42e
C_3 E_1	3.84d	3.84c	3.84b	4.78b	4.27e	3.80d
C_3 E_2	4.41c	4.80b	3.84b	4.77d	4.34d	3.88c
C_4 E_0	1.92g	1.92e	0.96d	8.80a	7.44c	6.31b
C_4 E_1	4.41c	3.84c	3.84b	8.81a	7.82b	7.15a
C_4 E_2	4.99b	4.80b	3.84b	8.82a	7.93a	7.16a
CV%	2.59	2.42	0.62	5.60	0.16	0.22
$LSD_{0.05}$	0.1569	0.1555	0.0307	0.35	0.009	0.02

N.B.: C_0=No chia seed, $C_1 = 6.25$ % chia seed, $C_2 = 12.5$ % chia seed, $C_3 = 25$ % chia seed, $C_4 = 50$ % chia seed, E_0 = No Essential Oil, $E_1 = 1000$ ppm Cinnamon Essential Oil, $E_2 = 1000$ ppm Lemon grass Essential Oil.

treatment ($C_4 = 50$ % chia seed).

4.8. Microbial activity

Essential oil's antimicrobial properties were evident in the study, as it effectively inhibited bacterial growth in the pineapple jam. This effect can contribute to extending the shelf life of the product and ensuring its safety for consumption. The maximum bacterial growth was recorded 780 CFU/mL from treatment ($C_2E_0 = 12.5$ % chia no Essential oil) in 90 days. The lowest bacterial growth was recorded 84 CFU/mL for treatment ($C_4E_2 = 50$ % chia seed and 1000 ppm Lemon grass Essential oil) in 30 days. Fig. 5 shows the effect of essential oil on bacterial count with storage period where essential oils were found to be effective to control bacterial growth and E_2 (Lemongrass Essential oil) showed the best result.

4.9. Determination of color

Colour of jam was determined by taking the samples by using colorimeter. From Table 6 it was observed that the jam lost its particular colour due to the reduction of its lightness. The lowest lightness was recorded 30.14 from sample C_2E_1 and the highest lightness was recorded 39.72 from sample C_4E_0.

4.10. General acceptability

Evaluation of general acceptability was done by measuring the spread ability, flavour, Taste, Texture from taking opinion from different personnel. They were given each sample and gave their opinion. From their opinion C_3E_2 was marked as the best sample.

5. Discussion

Jams are made from a variety of fruits and are widely consumed due to their inexpensive price, year-round availability, and organoleptic qualities. Since none of the ingredients utilized (fruits, sugar, pectin, and citric acid) are excellent sources of proteins and

Table 6
Effect of chia seed and essential oil on Moisture and Bacteria of pineapple jam.

Treatment	Moisture %			Bacteria (CFU/mL)		
	30 Days	60 Days	90 Days	30 Days	60 Days	90 Days
A. Chia Seed						
C_0	33.64a	33.63a	27.99a	521.00b	458.00c	490.00c
C_1	31.96b	31.95b	27.22b	480.33c	410.00d	482.11d
C_2	29.97c	25.22c	27.48c	591.00a	512.00a	544.00b
C_3	29.47d	23.65d	18.44d	340.00d	372.00e	436.00e
C_4	23.73e	17.97e	11.47e	228.00e	504.00b	654.00a
CV%	0.21	0.03	0.03	0.65	0.68	0.58
$LSD_{0.05}$	0.06	0.007	0.0068	2.7092	2.9515	2.9142
B. Essential oil						
E_0	29.18c	26.25c	21.08c	567.80a	608.40a	655.27a
E_1	29.41b	26.56b	21.28b	419.80b	420.00b	522.00b
E_2	29.47a	26.65a	21.61a	308.60c	325.20c	386.40c
CV%	0.21	0.03	0.03	0.65	0.68	0.58
$LSD_{0.05}$	0.04	0.005	0.005	2.0985	2.2863	2.2573
C. Combination						
C_0 E_0	33.24b	33.22c	27.72c	570.00c	582.00c	594.00e
C_0E_1	33.83a	33.83b	28.06b	525.00e	426.00h	468.00i
C_0E_2	33.85a	33.85a	28.20a	468.00h	366.00j	408.00k
C_1 E_0	31.93c	31.93f	27.01f	553.00d	744.00b	798.33a
C_1 E_1	31.98c	31.98d	27.32e	491.00g	336.00m	468.00i
C_1 E_2	31.97c	31.97e	27.34d	397.00i	150.00o	180.00n
C_2 E_0	29.96d	25.02i	21.43i	720.00a	762.00a	780.00b
C_2 E_1	29.99d	25.31h	21.51g	675.00b	522.00e	540.00g
C_2 E_2	29.98d	25.33g	21.50h	378.00j	252.00n	312.00m
C_3 E_0	29.19g	23.12l	18.12l	498.00f	420.00i	534.00h
C_3 E_1	29.51f	23.73k	18.23k	306.0k	354.00k	414.00j
C_3 E_2	29.70e	24.12j	18.98j	216.00l	342.00l	360.00l
C_4 E_0	21.60j	17.97n	11.13o	498.00f	534.00d	570.00f
C_4 E_1	21.73i	17.99m	11.27n	102.00m	462.00g	720.00c
C_4 E_2	21.86h	17.98m	12.01m	84.00n	516.00f	672.00d
CV%	0.21	0.03	0.03	0.65	0.68	0.58
$LSD_{0.05}$	0.10	0.01	0.012	4.6924	5.1122	5.0476

N.B.: C_0=No chia seed, $C_1 = 6.25$ % chia seed, $C_2 = 12.5$ % chia seed, $C_3 = 25$ % chia seed, $C_4 = 50$ % chia seed, E_0 = No Essential Oil, $E_1 = 1000$ ppm Cinnamon Essential Oil, $E_2 = 1000$ ppm Lemon grass Essential Oil.

Table 7
Effect of chia seed and essential oil on Colour of pineapple jam.

Treatment	L	a	b	C	h
C_0 E_0	33.20	4.74	11.39	12.34	67.40
C_0E_1	32.04	8.85	13.67	16.28	57.08
C_0E_2	39.52	9.95	19.42	21.82	62.88
C_1 E_0	32.63	5.12	11.70	12.77	66.37
C_1 E_1	31.50	5.50	10.80	11.50	64.39
C_1 E_2	30.82	4.70	9.30	10.42	63.19
C_2 E_0	34.64	5.72	13.34	14.51	66.80
C_2 E_1	30.14	5.01	10.03	11.21	63.44
C_2 E_2	34.81	5.80	13.05	14.28	66.03
C_3 E_0	36.90	5.53	13.03	14.16	67.00
C_3 E_1	34.73	4.52	9.74	10.74	65.11
C_3 E_2	38.17	5.89	12.91	14.19	65.47
C_4 E_0	39.72	5.77	12.98	14.20	66.01
C_4 E_1	32.61	4.77	10.31	11.37	65.16
C_4 E_2	36.51	5.60	12.89	14.05	66.53

N.B.: L = Lightness, a = Red/Green coordinate, b = Yellow/Blue coordinate, C = Chroma, h = Hue angle.

fat, the protein concentration in pineapple jam stays low. On the other hand, chia seeds boosted the protein content in direct proportion to their inclusion. Chia seeds have a greater protein content than the most popular grains, including wheat, barley, and oats, at about 16.5 %. According to studies, chia seeds have a high protein quality score because they contain both essential and non-essential amino acids like methionine, phenylalanine, cysteine, and glycine in significant amounts. As a result, they can be used as a supplement to foods with low protein quality, like pineapple jam. Since the pH of the chia seed-fortified jams ranged from 3.83 to 4.85 and that of the control pineapple jam was 4, it may be concluded that chia seeds had no significant effect on the pH. For the purpose of obtaining ideal gel conditions and product preservation, jam's pH is a crucial characteristic. The control and jam formulations had comparable

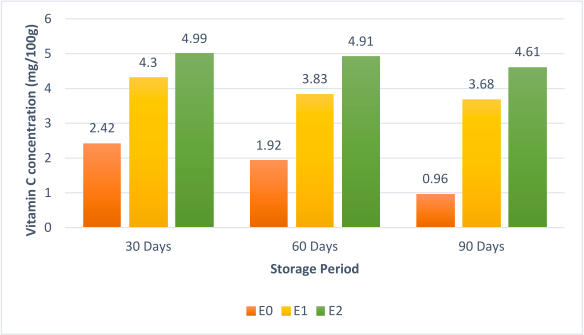


Fig. 3. Effect of Essential oil on vitamin C concentration (mg/100g) with storage period.

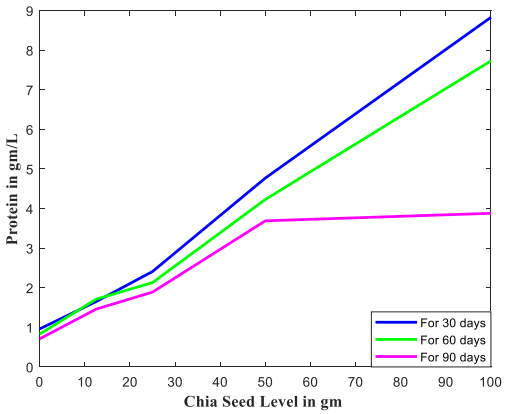


Fig. 4. Effect of Chia seed on protein content of jam with storage period.

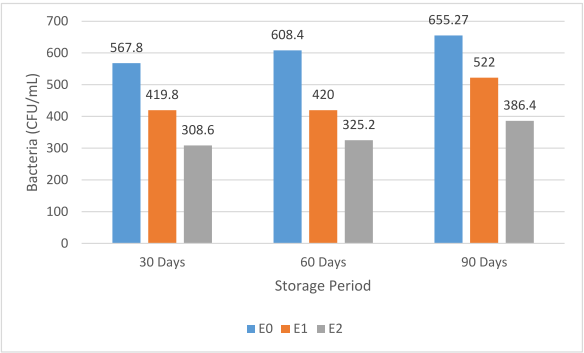


Fig. 5. Effect of Essential oil on bacterial count with storage period.

numbers, and the sugar content of the jams as determined by Brix barely altered. This might be because chia seeds contain 83 percent of their carbohydrates as fiber. The sugar in jam comprises the one in the fruits and the added sugar, which are crucial in the preservation of the product. Color and texture are important sensory qualities that influence consumer approval [2]. Chia seed addition at 6.25 % did not appreciably change the product's color or texture, indicating that larger chia seed concentrations would not be tolerated [32,33]. The use of whole chia seeds may have contributed to the low scores for the texture where chia seeds were used in higher concentrations. Although chia seeds have a mild flavor, this has a big impact on the jam's flavor. From the experiment it is found that protein content increased with addition of chia seed. On the other hand vitamin C content is increased in pineapple jam by addition of cinnamon and lemongrass essential oil. In 30 days, in case of E_0 (No essential oil) the amount of vitamin C in jam was 2.42 mg/100 g. For E_1 (1000 ppm Cinnamon Essential oil) vitamin C content was 4.3 mg/100g and for E_2 (1000 ppm Lemongrass Essential oil) vitamin C content was 4.99 mg/100 g. Moreover, E_2 (1000 ppm Lemongrass Essential oil) was found to be more effective in controlling

bacterial growth. The treatment C_1E_2(6.25 % Chia seed and 1000 ppm Lemongrass Essential oil) was recorded as the most controlled combination for bacterial growth. It should be emphasized that chia seed is regarded as a novel product that has just recently been introduced in Kenya, and as a result, it received low acceptability scores due to the lack of information available about its nutritional content. However, with sensitization, chia seed-based food product development is highly desirable and might be used for nutritional food items. We can conclude from the research that the treatment ($C_4E_2 = 50$ % chia seed and 1000 ppm Lemongrass Essential oil) showed best result in case of vitamin C retention and protein incorporation. But considering spreadability and general acceptability ($C_3E_2 = 25$ % chia seed and 1000 ppm Lemongrass Essential oil) can be considered as best treatment for consumers. One important point should be considered that, determining the optimal concentration of essential oils for vitamin C preservation without overpowering the jam's natural flavor is a challenge. Overuse of essential oils could result in a strong, unappealing taste, while underuse might render them ineffective in preserving vitamin C. Careful consideration for incorporating additives is essential.

6. Conclusion

Pineapple is a rich source of minerals like magnesium, sodium, potassium, phosphorus, calcium, iron, fiber, carbohydrate. Careful consideration of the desired product characteristics and consumer preferences is essential when incorporating the additives into pineapple jam formulations. The Analytical Hierarchy Process (AHP) is taken in the research to systematically evaluate and prioritize the best choices regarding the essential oils and chia seed fortification, balancing multiple complex criteria to achieve the desired outcome in pineapple jam production.

The overall time complexity could be represented as the main experimental and data collection processes. The most time-consuming parts are experimentation and data analysis, which determine the overall complexity. The sensitivity analysis highlights the delicate balance needed when optimizing essential oil concentrations and chia seed fortification in pineapple jam. The study's outcome depends significantly on how well these variables are controlled and fine-tuned to achieve optimal preservation, nutritional enhancement, and consumer acceptance. However, the incorporation of essential oil and chia seeds in pineapple jam formulation has several notable effects. Chia seeds increase protein content but may not affect pH, Brix level, and vitamin C concentration significantly. Essential oil exhibits with less microbial attack, enhancing shelf life and maintaining product safety [22]. Additionally, chia seeds can impact moisture content, potentially influencing texture. These findings highlight the multifaceted nature of these additives in pineapple jam production, offering opportunities to create products with enhanced nutritional profiles and extended shelf life [23]. The findings could be valuable for the food industry, particularly in the development of natural preservatives and nutrient-dense products. This could lead to innovations in the production of other fruit-based preserves or processed foods. This offers a healthier and more nutrient-dense alternative to conventional jams, addressing micronutrient deficiencies in communities. Using essential oils as natural preservatives reduces the reliance on synthetic preservatives, which are often costly and less environmentally friendly. This can lower production costs and provide affordable, healthier food options for consumers. Innovative, health-oriented products like fortified pineapple jam have the potential to capture niche markets, both locally and internationally. This can boost small and medium enterprises (SMEs) in the food industry, stimulating economic growth [20]. Fortified and preservative-enhanced products have export potential due to their longer shelf life and unique health benefits. Developing such products can help countries improve their trade balance and earn foreign exchange.

In summary, the findings could be valuable for the food industry, particularly in the development of natural preservatives and nutrient-dense products. From the investigation it may be said that more future works can be done using these super food in citrus or other fruit jam, jelly or marmalade. This could lead to innovations in the production of other fruit-based preserves or processed foods. This research contributes to health, agriculture, sustainability, and economic development by promoting natural, nutrient-enhanced food products with broad socio-economic impacts.

CRediT authorship contribution statement

Tanima Jarin: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Md Nazrul Islam:** Writing – review & editing, Supervision. **Shormin Choudhury:** Writing – review & editing, Supervision. **Md Rabiul Islam:** Writing – review & editing, Visualization, Validation, Software, Formal analysis. **Reana Raen:** Writing – review & editing, Visualization, Validation, Software. **Redwanul Islam:** Writing – review & editing, Visualization, Validation, Software. **Sika Mustaki:** Visualization, Validation, Methodology.

Informed consent

Clearly state that participants provided informed consent.

Ethical statement

This material is the authors' own original work, which has not been previously published elsewhere. The paper is not currently being considered for publication elsewhere. The paper reflects the authors' own research and analysis in a truthful and complete manner. All authors have been personally and actively involved in substantial work leading to the paper, and will take public responsibility for its content. I agree with the above statements and declare that this submission follows the policies as outlined in the

Guide for Authors and in the Ethical Statement.

Data availability

Data will be made available on request.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2024.e40711.

References

[1] V.O. Ajibola, O.A. Babatunde, S. Suleiman, The effect of storage method on the vitamin C content in some tropical fruit juices, Trends Appl. Sci. Res. 4 (2) (2009) 79–84.
[2] G. Sacchetti, et al., Comparative evaluation of 11 essential oils of different origin as functional antioxidants, antiradicals and antimicrobials in foods, Food Chem. 91 (4) (2005) 621–632.
[3] Y. Ding, et al., Nutritional composition in the chia seed and its processing properties on restructured ham-like products, J. Food Drug Anal. 26 (1) (2018) 124–134.
[4] E.C. Egan, H. Kirk, R.S. Sawyer, Pearson's chemical analysis of foods, Off. J. Eur. Union 52 (294) (1985) 1–40.
[5] J.H. Kang, B.W. Ahn, D.H. Lee, H.S. Byun, S.B. Kim, Y.H. Park, Inhibitory effects of ginger and garlic extracts on the DNA damage, Korean J Food Sci Food 20 (3) (1988) 287–292.
[6] Y. Guo, et al., Advances in the role and mechanisms of essential oils and plant extracts as natural preservatives to extend the postharvest shelf life of edible mushrooms, Foods 12 (4) (2023).
[7] E.A. Azooz, F.A. Wannas, R.K. Ridha, S.K. Jawad, E.A.J. Al-Mulla, A green approach for micro determination of silver(I) in water and soil samples using vitamin C, Anal. Bioanal. Chem. Res. 9 (2) (2022) 133–140.
[8] A. Uckiah, D. Goburdhun, A. Ruggoo, Vitamin C content during processing and storage of pineapple, Nutr. Food Sci. 39 (4) (2009) 398–412.
[9] M.R. Segura-Campos, N. Ciau-Solís, G. Rosado-Rubio, L. Chel-Guerrero, D. Betancur-Ancona, Chemical and functional properties of chia seed (salvia hispanica L.) gum, Int. J. Food Sci. 2014 (2014) 241053.
[10] Y.P. Timilsena, R. Adhikari, C.J. Barrow, B. Adhikari, Physicochemical and functional properties of protein isolate produced from Australian chia seeds, Food Chem. 212 (2016) 648–656.
[11] F.A. Toves, Nutrient-fortified, Reduced Calorie Fruit And/or Vegetable Food Product and Processes for Making Same, U.S, 2004.
[12] M.Á. Valdivia-López, A. Tecante, Chia (salvia hispanica): a review of native Mexican seed and its nutritional and functional properties, Adv. Food Nutr. Res. 75 (2015) 53–75.
[13] C. Muresan, A. Pop, S. Muste, S. Scrob, A. Rat, Study concerning the quality of jam products based on banana and ginger, J. Agroaliment. Process. Technol. 20 (4) (2014) 408–411.
[14] S. Nitrayová, M. Brestenský, J. Heger, P. Patráš, J. Rafay, A. Sirotkin, Amino acids and fatty acids profile of chia (Salvia hispanica L.) and flax (Linum usitatissimum L.) seed, Potravinarstvo 8 (2014) 72–76.
[15] M.R. Segura-Campos, N. Ciau-Solís, G. Rosado-Rubio, L. Chel-Guerrero, D. Betancur-Ancona, Chemical and functional properties of Chia seed (Salvia hispanica L.) gum, Intern. J. Food Sci. (2014).
[16] C. Society, D.C. Washington, S. Garg, P. Gosh, S.S. Rama, R.C. Pradahan, Preparation and quality evaluation of nutritionally enriched jam made from blends of Indian blackberry and other fruits, Int. J. Fruit Sci. 19 (1) (2019) 29–44.
[17] Y. Ding, et al., Nutritional composition in the chia seed and its processing properties on restructured ham-like products, J. Food Drug Anal. 26 (1) (2018) 124–134.
[18] N. Guerrero, S.M. Alzamora, Effect of pH, temperature and glucose addition on flow behavior of fruit purees: peach, papaya, and mango puree, J. Food Eng. 33 (1998) 239–256.
[19] R.K. Ridha, D.H. Alasady, E.A. Azooz, W.I. Mortada, Rapid synergistic cloud point extraction based on hydrophobic deep eutectic solvent combined with hydride generation atomic absorption spectrometry for determination of selenium in tea samples, J. Food Compos. Anal. 132 (2) (2024).
[20] R.A. Abraham, T.J. Joshi, S. Abdullah, A comprehensive review of pineapple processing and its by-product valorization in India, Food Chem. Advan. 3 (2023).
[21] G.M. Sun, X.M. Zhang, A. Soler, P.A.M. Alphonsine, Chapter 25-nutritional composition of pineapple (ananas comosus (L.) Merr. Nutritional Composition of Fruit Cultivars, 2016, pp. 609–637.
[22] D. Byarushengo, R. Minja, A. Temu, Lemongrass and cinnamon essential oils as vitamin C preservatives and flavour enhancers in jam, Tanzania J. Eng. Technol. 35 (1) (2014) 46–53.
[23] J.M. Nduko, R.W. Maina, R.K. Muchina, S.K. Kibitok, Application of chia (*Salvia hispanica*) seeds as a functional component in the fortification of pineapple jam, Food Sci. Nutr. 6 (8) (2018) 2344–2349.
[24] F. Gómez, M. Igual, M.J. Pagán, M.M. Camacho, Changes in the microbiological and physicochemical quality during storage of osmotically dehydrated strawberry jam stabilized with plant extracts, CyTA - J. Food 11 (3) (2013) 248–255.
[25] M.N. Mohd Naeem, et al., The nutritional composition of fruit jams in the Malaysian market, J. Saudi Soc. Agric. Sci. 16 (1) (2017) 89–96.
[26] E. Afoakwa, E. Nartey, J. Ashong, G. Annor, Effect of sugar, pectin and acid balance on the quality characteristics of pineapple (Ananas comosus) jam. Proceeding of the 13th World Food Congress, 2006, pp. 1–2.
[27] M.M. Ali, N. Hashim, S. Aziz, O. Lasekan, Pineapple (Ananas comosus): a comprehensive review of nutritional values, volatile compounds, health benefits, and potential food products, Food Res. Int. (2020).
[28] B.J. Olson, J. Markwell, Assays for determination of protein concentration, Curr Protoc Protein Sci. (2007). Chapter 3, Unit 3.4.
[29] J.Y. Ahn, D.Y. Kil, C. Kong, B.G. Kim, Comparison of oven-drying methods for determination of moisture content in feed ingredients, Asian-Australas. J. Anim. Sci. 21 (11) (2014) 1615–1622.
[30] S. Bhuyan, M. Yadav, S.J. Giri, S. Begum, S. Das, A. Phukan, P. Priyadarshani, S. Sarkar, A. Jayswal, K. Kabyashree, A. Kumar, M. Mandal, S.K. Ray, Microliter spotting and micro-colony observation: a rapid and simple approach for counting bacterial colony forming units, J. Microbiol. Methods 207 (2023).

[31] K.A. Gomez, A.A. Gomez, Statistical Procedures for Agricultural Research, second ed., John Wiley & Sons, Nashville, TN, 1984.
[32] M.N. Mohd Naeem, et al., The Nutritional Composition of Fruit Jams in the Malaysian Market, 2017.
[33] M. Hadidi, et al., Polysaccharides from pineapple core as a canning by-product: extraction optimization, chemical structure, antioxidant and functional properties, Int. J. Biol. Macromol. 163 (2020) 2357–2364.