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Preparation and Characterization of Pumpkin (Cucurbita spp.) Jam: Nutritional Composition, Antioxidant Activity, and Sensory Evaluation of Different Varieties

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ABSTRACT

Pumpkin is a nutrient-rich vegetable with potential as a functional food, yet much of its pulp remains underutilized. This study aimed to prepare jams from different pumpkin varieties and evaluate their proximate composition, antioxidant activity, and sensory attributes. Physicochemical analyses included moisture, ash, fat, fiber, protein, carbohydrate, pH, total sugar, TSS, and energy, while bioactive compounds such as phenol, flavonoid, β-carotene, and DPPH scavenging activity were also measured. Results showed that β-carotene was highest in S2 (*C. maxima*, 4.46 mg/100 g), protein (2.46 g/100 g) and fiber (5.06 g/100 g) were also highest in S2, while carbohydrate content was highest in S3 (*C. moschata*, 65.22 kcal). pH ranged from 5.01 to 5.39, total sugar was highest in S2 (82.52 g/100 g), TSS was highest in S2 (69.63°Brix), and energy was highest in S3 (270.33 kcal). Flavonoid and DPPH scavenging activity showed no significant differences, while total flavonoid content was highest in S1 (21.26 mg QE/100 g). Sensory evaluation revealed no significant differences in color, flavor, and consistency, but taste and overall acceptance were highest in S3. These findings indicate that pumpkin jam is a nutritious, energy-rich product with antioxidant properties and high β-carotene content, suitable as a health-promoting snack.

1-Introduction

Pumpkin (Cucurbita spp.), a nutrient-rich vegetable of the family Cucurbitaceae, is cultivated globally and valued for its edible pulp and bioactive compounds. Its flesh is abundant in carotenoids, vitamins, minerals, and dietary fiber, which contribute to nutrition and health promotion [1]. Despite high worldwide production, pumpkin flesh often remains underutilized, leading to considerable post-harvest losses [2-3]. Recent research emphasizes the utilization of pumpkin flesh in value-added products such as jams, which can enhance consumer acceptability, reduce wastage, and contribute to functional food development [4-6]

Globally, pumpkin cultivation covers over 3 million hectares, producing approximately 27.8 million tons annually, with China and India accounting for 58% and 20% of production, respectively [7]. Despite this extensive cultivation, pumpkin remains underutilized in food product development, particularly regarding its flesh [8]. Pumpkin is considered a rich source of bioactive compounds, including flavonoids, phenolic acids, and lignans, which exhibit anti-inflammatory, antimicrobial, anticancer, and immunomodulatory properties, supporting disease prevention and overall health [9]. Additionally, pumpkin contains antioxidants such as β-carotene, vitamin C, and vitamin E, which protect cells from oxidative stress, reducing the risk of chronic diseases, including cardiovascular disorders, cancer, and age-related macular degeneration [10].

Recent studies also highlight the presence of carotenoids, tocopherols, phenolic compounds, polysaccharides, and essential minerals in pumpkin, making it a promising candidate for functional food research and development [11-12]. Accordingly, current functional food studies increasingly focus on pumpkin due to its pharmacological and biomedical applications [6][9]. Pumpkin flesh constitutes approximately 70–76% of the fruit's weight and is rich in natural sugars, pectin, essential minerals (e.g., potassium and magnesium), and vitamins A, C, and E [2-3]. Despite these nutritional benefits, a substantial portion of pumpkin flesh is discarded or relegated to low-value uses such as animal feed or composting, representing missed opportunities for food waste reduction and value addition [13].

Processing pumpkin into value-added products like jams provides a sustainable approach to mitigate these issues. Jam production not only extends shelf life but also ensures pumpkin availability during off-seasons [4]. The natural pectin content supports gel formation, contributing to the texture and structural stability of jams, while natural sugars and fiber enhance both flavor and nutritional quality [14][3]. Moreover, incorporating functional ingredients, such as porang flour, can improve texture, antioxidant capacity, total phenolic content, and sensory appeal of pumpkin jam, aligning with current trends in functional foods and nutraceuticals [15-16][6].

Thus, transforming pumpkin flesh into jam represents a strategic intervention to reduce food waste, maximize nutritional potential, and introduce marketable, health-promoting products. This approach contributes to food security, economic sustainability, and consumer health, addressing the global challenge of food loss, which is estimated at 1.3 billion tons annually (United Nations Environment Programme, 2021).

2-MATERIALS AND METHODS

Criteria for Selection of Cucurbita Varieties

The Cucurbita varieties evaluated in this study were selected based on their local availability, agronomic importance, and common use for human consumption in the study region. These varieties are widely cultivated by local farmers due to their high yield potential, adaptability to agro-climatic conditions, and consumer preference. In addition, preliminary information from existing literature and local agricultural sources indicated potential differences among these varieties in nutritional composition and phytochemical content, which justified their comparative evaluation for jam production.

Sample Collection

Fresh and physiologically mature pumpkins of three species *Cucurbita pepo*, *Cucurbita maxima*, and *Cucurbita moschata* were collected from local farms and markets in the Dinajpur district during the peak harvesting season. Selection was based on uniformity in size and shape, absence of physical damage, and freedom from insect infestation or fungal contamination. Maturity was confirmed through characteristic indicators such as hardened rind, species-specific coloration, and peduncle senescence. Following collection, the pumpkins were stored at ambient room temperature under clean, dry conditions prior to subsequent analyses.

a) *Cucubitace pepo* b) *Cucubitace maxima* c) *Cucubitace moschata*

Figure 1: Freshly collected Pumpkin

Chemicals and Reagents

All chemicals and reagents used in the study were of analytical grade. The following were procured and utilized for different experimental analyses: gallic acid, Folin–Ciocalteu reagent (FCR), sodium carbonate (Na_2CO_3), sodium nitrite ($NaNO_2$), aluminum chloride ($AlCl_3$), sodium hydroxide (NaOH), vanillin, hydrochloric acid (HCl), 2,2-diphenyl-1-picrylhydrazyl (DPPH), disodium hydrogen phosphate dihydrate ($Na_2HPO_4 \cdot 2H_2O$), sodium dihydrogen phosphate dihydrate ($NaH_2PO_4 \cdot 2H_2O$), potassium ferricyanide [$K_3Fe(CN)_6$], trichloroacetic acid (TCA), ferric chloride ($FeCl_3$), ferrous sulfate heptahydrate ($FeSO_4 \cdot 7H_2O$), sulfuric acid (H_2SO_4), sodium potassium tartrate, 3,5-dinitrosalicylic acid (DNS), phenol, methanol, ethanol, acetone, and hexane.

Table 1: Formulation of pumpkin jam:

Ingredients	S_1	S_2	S_3
Pumpkin pulp(g)	100	100	100
Sugar(g)	50	50	50
Pectin(g)	1	1	1
Lemon Juice(mL)	5	5	5
Orange Juice (mL)	5	5	5
Spices(g)	2	2	2
Salt(g)	2	2	2

Here, S_1= *Cucurbitace pepo,* S_2 = *Cucurbitace maxima*, S_3= *Cucurbitace Moschata*

Jam formulation and processing conditions

The jam formulation and processing conditions were identical for all pumpkin (Cucurbita spp.) varieties. A single, standardized formulation (pumpkin pulp, sugar, pectin, and citric acid at fixed ratios) (Table 1) was applied to all samples to ensure that differences observed among jams were attributable solely to varietal characteristics. The formulation and processing parameters were optimized through preliminary trials using a representative pumpkin variety. Optimization focused on achieving acceptable gel consistency, balanced sweetness and acidity, proper texture, and a target total soluble solids level (°Brix) consistent with standard jam quality requirements. Cooking temperature, time, and endpoint (based on °Brix and gel formation) were fixed after optimization and strictly maintained for all varieties to ensure reproducibility and meaningful comparison.

Preparation of pumpkin jam

Pumpkin jam (All varieties) was prepared following Sindumathi and Amutha [17] with minor modifications. Grated pumpkin was transferred into an open stainless-steel pan (5 L, LabTech) and heated to boiling. Low-methoxyl pectin (LMP, 104 AS-FS, E 440a) was added at 1% (w/w) and boiled for 10 min to ensure complete dissolution. Sugar was then incorporated, and the mixture was continuously heated over a low flame. The total soluble solids (TSS) of the mixture were monitored using a digital refractometer. When TSS reached 60 °Brix, freshly extracted orange juice and lemon juice were added as a source of citric acid, and the mixture was homogenized by continuous stirring with a stainless-steel ladle (30 cm, LabTech). Heating was continued until the TSS reached 67–68 °Brix. The hot jam was aseptically filled into sterilized glass jars (250 mL) and allowed to cool to ambient temperature. The prepared pumpkin jam was stored at room temperature until further physicochemical and sensory analyses.

Sample extraction

1 g of sample was dissolved in 19 mL of 100 % methanol. It was then stirred for 20 min on a magnetic stirrer at 100 revolutions per minute (rpm). The mixture was faltered through a filter paper (Whatman No. 41) and the filtrate was kept in the dark at 4 °C until further analysis.

Proximate analysis of Pumpkin Jams

Moisture, protein, ash, fiber, and fat content of pumpkin jam were determined according to the method explained in A.O.A.C. [18]. Total carbohydrate was calculated by difference: 100 –
(moisture + ash + protein + fat + crude fiber), while energy values were calculated using Atwater factors (4 kcal/g for protein, 4 kcal/g for carbohydrate, and 9 kcal/g for fat). pH was measured with a digital pH meter (Jenco-6177M, China) after calibration with pH 4.0 and 7.0 buffers, and total soluble solids (TSS) were determined using a refractometer (HANNA HI 96800, USA) calibrated with distilled water and expressed as °Brix. Color parameters (L*, a*, and b*) of the samples were measured using a colorimeter (Model ZE6000, Nippon Denshoku Co., Japan). The color intensity (chroma, *C**), visual color appearance (hue angle, *h**), browning index (*BI*), yellowness index (*YI*) was calculated according to Equations $C*=\sqrt{a*^2+b*^2}$; $h*=\tan^{-1}(b*/a*)$; $YI=142.86\ b*/L*$; $BI=100\times(X-0.310.17)$ where $X=(a*+1.75\times L*)$ / $(5.645\times L*+a*-3.012\times b)$ respectively.

Determination of β-carotene

The β-carotene content of flour samples was determined following the method described by Halim et al. [19]. A solvent mixture of acetone and hexane (4:6, v/v) was prepared. Exactly 1.00 g of sample was homogenized with 15 mL of the solvent mixture using a homogenizer (Ultra-Turrax T25, IKA, Staufen, Germany). The homogenate was centrifuged at 3600 rpm (2000g) for 10 min at room temperature in a centrifuge (Hettich Rotina 380R, Tuttlingen, Germany). The resulting supernatant was collected, and an aliquot was transferred into a quartz cuvette. Absorbance was measured at 453 nm, 505 nm, and 663 nm using a UV–Vis's spectrophotometer (Shimadzu UV-1800, Kyoto, Japan). The β-carotene content was calculated using the following equation:

$\beta-\text{Carotene (mg/100 g)} = 0.216A_{663}-0.304A_{505}+0.452A_{453}.$

Determination of Total Phenolic Content (TPC)

The total phenolic concentration of the extracts was assessed using a spectrophotometric approach adapted from Rahman et al. [20]. In this method, gallic acid served as the calibration standard, while Folin–Ciocalteu reagent functioned as the oxidizing agent. Absorbance readings were taken at 725 nm with a UV/VIS spectrophotometer (UV-1800, Shimadzu, Japan). The TPC values were derived from the gallic acid standard curve (0–210 µg/g) and expressed as micrograms of gallic acid equivalents per gram of dry weight (µg GAE/g DW).

Determination of Total Flavonoid Content (TFC)

Flavonoid concentration was quantified using a modified version of the colorimetric procedure outlined by Islam et al. [21]. The absorbance of the test solution was recorded at 510 nm employing a UV/VIS spectrophotometer (UV-1800, Shimadzu, Japan). Catechin was used to establish the calibration curve (0–750 µg/g). Results were expressed as micrograms of catechin equivalents per gram of dry weight (µg CE/g DW).

Determination of DPPH Radical Scavenging Activity

The antioxidant activity of the extracts was determined using the DPPH radical scavenging assay, following the protocol of Rahman et al. [20] with slight adjustments. The decrease in absorbance was monitored at 517 nm using a UV/VIS spectrophotometer (UV-1800, Shimadzu, Japan). Trolox served as the reference compound (0–260 µg/g), and the results were reported as micromoles of Trolox equivalents per gram of dry weight (µmol TE/g DW.)

Determination of Total Sugar Content

Briefly, 500 mg of the sample was placed into a 50 mL beaker and mixed with 10 mL of 80% ethanol. The mixture was homogenized and centrifuged at 2000 rpm for 20 minutes. From the resulting supernatant, 1 mL was transferred into a clean test tube and combined with 1 mL of 5% phenol solution. Subsequently, 5 mL of 95.5% sulfuric acid was added. The mixture was left to stand for 10 minutes, vortexed for 30 seconds, and then incubated at room temperature in a water bath for 20 minutes to allow color development. Absorbance was measured at 490 nm using a UV/VIS spectrophotometer (UV-1800, Shimadzu, Japan). A calibration curve was generated with glucose standards, and the total sugar content was expressed as mg per 100 g of sample.

Organoleptic evaluations

Organoleptic evaluation was carried out by twenty five students and teachers selected from the Faculty of Engineering, Hajee Mohammad Danesh Science and Technology University, Dinajpur, on a 9-point hedonic scale (9 – like extremely, 8 – like very much, 7 – like moderately, 6 – like slightly, 5 – neither like nor dislike, 4 – dislike slightly, 3 – dislike moderately, 2 – dislike very much, and 1 – dislike extremely) for appearance, color, aroma, taste, texture, and overall acceptability of the product. The coded samples were served in clean white plastic cups in individual booths under adequate fluorescent light. Sample presentation to the panelists was at random and one at a time. They were provided samples to drinking and check how much they liked or disliked each one and rate them as such. The panelists were advised to wash their mouths with enough water between each serve.

Statistical analyses

All the experiments for each sample were done in triplicates. Results are presented as means ± standard deviation. Statistical analysis was performed (SPSS for windows version 25.0) by one way analysis of variance (ANOVA). Mean comparisons were performed using Duncan's multiple range tests for significant effect at ($p \leq 0.05$).

3-RESULTS AND DISCUSSION

Color is a critical quality attribute influencing consumer perception and acceptance. Instrumental analysis of three pumpkin jam samples (S1, S2, S3) revealed subtle differences in lightness (L), redness (a*), *yellowness* (b*), chroma (C*), hue angle (h°), yellowness index (YI), and browning index (BI). S1 exhibited the most intense red-orange coloration (L* = 29.37, a* = 9.50), with the highest chroma (C* = 17.03), yellowness (YI = 68.78), and browning (BI = 86.57), indicating a deeper and more vivid hue. S3 was lighter (L* = 33.32) with lower redness (a* = 6.27) and chroma (C* = 16.37), and a higher hue angle (h° = 67.48), reflecting a shift toward yellow-orange tones. S2 showed intermediate values. These findings are consistent with prior research showing that pumpkin jams retain their delicious yellow-orange colors across different types. In Cucurbita maxima and C. pepo, Chikpah et al. [22] observed that drying temperature influences pumpkin color, with higher temperatures increasing browning and decreasing yellowness. In addition, processing variables (temperature and time) and possibly cultivar type affect the values of these color characteristics. According to Zhang et al. [3] the stability of color in the samples may be influenced by factors like oxygen, pH, temperature, illumination, sugar levels, the presence of ascorbic acid or certain metal ions, and the quantity of pigment in both fresh products and thermally processed. During the puree production process, color changes are inevitable because of the generation of browning and yellowing substances, Maillard reactions, and the polymerization of anthocyanins with certain phenolic compounds [23].

Table 2: Color parameters

Parameter	S1	S2	S3
L*	29.37 ± 0.39	32.14 ± 0.22	33.32 ± 0.38
a*	9.50 ± 0.41	7.40 ± 0.45	6.27 ± 0.36
b*	14.14 ± 0.26	15.21 ± 0.51	15.12 ± 0.39
C*	17.03 ± 0.31	16.91 ± 0.50	16.37 ± 0.39
h* (°)	56.10 ± 1.24	64.06 ± 1.57	67.48 ± 1.28
YI	68.78 ± 1.56	67.61 ± 2.31	64.83 ± 1.83
BI	86.57 ± 2.34	78.50 ± 3.04	72.06 ± 2.38

Values are expressed as mean ± standard deviation (n = 3)

Nutritional Composition

Moisture content is a critical factor influencing the shelf life, texture, and microbial stability of food products, as higher moisture levels generally promote microbial growth and reduce product stability, whereas lower moisture helps in prolonging shelf life (Fellows, 2000). In the present study, significant differences ($p \leq 0.05$) were observed among the three jam samples with respect to moisture content. Sample S1 exhibited the highest moisture content at 29.68%, followed by S2 at 28.50%, while S3 recorded the lowest value of 28.11%. Consistent with these results, Salem et al. [24] observed that the moisture of chia-fortified pumpkin jam decreased from 35.9% to 30.2% after fortification, showing the influence of ingredient addition on moisture behavior. Apolonio [25] mentioned that the moisture of starfruit jam varied between 27% and 31% depending on the type of sugar habituated which supports our result as a variable factor moreover. This difference between the samples would indicate that differences on formulation, ingredients or processing conditions are an important factor regarding water retention in jams. Taken together, these results could imply that the maintenance of adequate moisture plays a pivotal role in not only achieving the desired sensory and textural quality, safety from spoilage pathogens and storage stability but also in having a positive impact on the overall shelf life.

Ash content indicates the total mineral composition of the product that consists of elements such as calcium, potassium, magnesium, sodium, iron and phosphorus, which are important inorganic nutrient factors. The differences were also significant ($p \leq 0.05$) between samples S1 (1.16%) and the others, being higher than their levels in samples S3 (1.03%) and S2 (0.92%). Large ash content reflects high mineral content that may depend on raw materials, proportion of formulation and processing conditions. In a similar investigation, Benmeziane-Derradji et al. [26], who found that replacing sugar partially with honey in the pumpkin jam increased ash contents due to the minerals present in the natural honey like potassium, calcium and iron. Similarly, Chalchisa et al. [27] found that sugar concentrations and processing temperatures could change mineral retention in pineapple jam. These results emphasize the importance of both ingredient combination and process conditions on final fruit-based product mineral content. During jam production, the heat allows for concentration of soluble solids, and partial collapse or volatilization of some compounds can occur; nevertheless, minerals are generally considered to be stable at this stage. High processing temperature and long cooking time together produce a condensing effect that can increase the ash percent by removing water. On the other hand, an over heat treatment or a filtration will clip minerals slightly. In addition, the mineral composition is different between the fruits themselves, and also varies with cultivar, soil contents and ripening stages possibly influence on differences of ash content among samples.

The protein in the pumpkin jam samples were S2 (2.46%), S3 (1.74%) and S1 (1.70%), respectively, as showing a significant difference ($p \leq 0.05$) of all three formulations. The observed variation is likely due to variations in the raw materials and their proportions, as well as impact of processing conditions on protein stability. Garg et al. [28] found similar-values for protein content in mixed jams of Indian blackberry and also speculated that fruit proteins and pectin–protein reactions could account for nitrogen detected within these products. These interactions are known to influence the texture and stability of jams by enhancing the gel matrix. Similarly, Saleem et al. [24] reported a slight increase in protein content when pumpkin jam was enriched with chia seeds, attributing the improvement to the high protein level and amino acid composition of the seeds. In the present study, the relatively higher protein content observed in S2 may be linked to the synergistic effect of ingredients that naturally contain more protein or retain nitrogenous compounds during cooking. Moreover, minimal protein denaturation could have occurred in S2, possibly due to optimized heating conditions or shorter cooking duration, which preserve thermolabile compounds.

Fat levels in the present study were low (0.01–0.02%) but differed significantly ($p \leq 0.05$) among the pumpkin jam samples. Such minimal fat content is typical of fruit-based products, as fruits generally contain negligible lipid fractions compared to cereals or oilseeds. The observed variation may result from differences in formulation or the proportion of pumpkin pulp incorporated, since trace amounts of lipids can originate from pumpkin seeds or other minor ingredients used in the jam preparation. Tuolienuo and Galyuoni [29] reported comparatively higher fat levels (2.56–3.00%) in pineapple–pumpkin blends, where increasing the proportion of pumpkin pulp slightly elevated lipid concentration due to the natural seed-derived oil fraction present in pumpkin. Similarly, Anwar et al. [30] observed an increase in fat content from 0.28% to 0.63% in papaya jam fortified with date pit powder, attributing the rise to the addition of lipid-rich plant materials. These findings suggest that the inclusion of fat-bearing ingredients, even in small amounts, can influence the overall lipid content of jams and preserves. In contrast, the minimal fat content recorded in the current pumpkin jam formulations contributes to better oxidative stability, as lower lipid concentrations reduce the risk of rancidity during storage. Moreover, low-fat content aligns with consumer preferences for healthier, shelf-stable fruit preserves. Overall, the results indicate that pumpkin jam is a naturally low-fat product with desirable storage characteristics and nutritional appeal for health-conscious consumers.

Table 3. Nutritional Composition of different pumpkin jam samples

Components	**S1 *(Cucurbita pepo)***	**S2 *(Cucurbita maxima)***	**S3 *(Cucurbita moschata)***
Moisture (%)	29.68 ± 0.05^{a}	28.50 ± 0.18^{b}	28.11 ± 0.08^{c}
Ash (%)	1.16 ± 0.08^{a}	0.92 ± 0.09^{b}	1.03 ± 0.09^{ab}
Fat (%)	0.01 ± 0.01^{c}	0.02 ± 0.01^{a}	0.02 ± 0.01^{b}
Protein (%)	1.70 ± 0.10^{b}	2.46 ± 0.14^{a}	1.74 ± 0.13^{b}
Fiber (%)	4.27 ± 0.28^{b}	5.06 ± 0.15^{a}	4.56 ± 0.31^{ab}
Carbohydrate (%)	62.40 ± 0.94^{b}	63.17 ± 0.71^{b}	65.22 ± 0.62^{a}
TSS (°Brix)	67.47 ± 1.11^{b}	69.63 ± 1.12^{a}	68.63 ± 0.61^{ab}
pH	5.39 ± 0.08^{a}	5.24 ± 0.10^{a}	5.01 ± 0.08^{b}

Components	S1 *(Cucurbita pepo)*	S2 *(Cucurbita maxima)*	S3 *(Cucurbita moschata)*
Total sugar (g/100 g)	78.07 ± 0.45^{c}	82.52 ± 0.36^{a}	80.13 ± 0.64^{b}
Energy (kcal)	256.95 ± 1.49^{c}	263.50 ± 1.01^{b}	270.33 ± 1.68^{a}

Values are expressed as mean ± standard deviation (n = 3). Different superscript letters within the same row indicate significant differences ($p \leq 0.05$) among the samples.

Crude fiber content varied significantly among the pumpkin jam samples, with the highest value observed in S2 (5.06%), followed by S3 (4.56%) and S1 (4.27%). These differences may be attributed to variations in the proportion of pumpkin pulp, the inclusion of fiber-rich additives, and processing conditions that affect fiber solubility and retention. The results are consistent with the findings of Akubor et al. [31], who reported that the addition of porang flour significantly increased the fiber content in pumpkin jam due to the presence of glucomannan a soluble dietary fiber known to enhance textural consistency and water-holding capacity in gel-based foods. Similarly, Ho et al. [32] observed moderate fiber levels (3.8%) in reduced-calorie belimbi jam, suggesting that both ingredient type and formulation adjustments influence the total fiber content of fruit preserves. In jam production, thermal processing can partially break down insoluble fibers into soluble fractions, which contribute to improved viscosity and mouthfeel. Therefore, the relatively high fiber values in the present study may also reflect efficient retention of both soluble and insoluble fiber components during cooking. The elevated crude fiber content in these pumpkin-based jams highlights the nutritional advantage of pumpkin as a natural source of dietary fiber. Dietary fibers play a crucial role in maintaining digestive health, regulating blood glucose and lipid levels, and promoting satiety. Hence, the findings indicate that pumpkin jam can be considered a functional food product with potential health benefits beyond basic nutrition, offering value-added appeal to health-conscious consumers.

The pumpkin jam samples showed significant differences ($p \leq 0.05$) in the carbohydrate content, with a higher percentage found for S3 (65.22%) followed by S2 (63.17) and then S1 (62.40%). The differences in carbohydrate content are mainly due to sugar addition, fruit pulp concentration and extent of water evaporation during cooking. In the case of fruit-based preserves, carbohydrates are mainly sugar (glucose, fructose and sucrose) with small amounts of pectic polysaccharides and other soluble fibers. Chalchisa et al. [27] observed carbohydrate values between 64% and 68% in pineapple jams, while it was found that higher levels of sugar and pectin led to an increase in TSS. Similarly, Makki et al. [32] date pumpkin jams were reported to a 70% in carbohydrate, emphasizing the influence of high-sugar contents and concentration effect during thermal processing. The present results are consistent with those of the previous study suggesting that not only ingredient combination, but also processing severity significantly influences carbohydrate profile. The high value of carbohydrate in S3 may also suggest that it probably contained more added sugar or dry matter loss during cooking was minimized, thus enhancing the concentration of soluble solids. From a texture standpoint, sweetness, spread ability and gel set properties are directly influenced by the composition of carbohydrates; which are essential factors influencing consumers acceptation. Thus, the findings show that suitable sugar and fruit solids content not only determine the nutritional quality but also develop the sensory and preservative character of pumpkin jam.

The physicochemical properties of pumpkin jam samples, encompassing total soluble solids (TSS), pH, total sugar, and energy content, exhibited significant variations ($p \leq 0.05$) among the formulations. TSS values ranged from 67.47°Brix (S1) to 69.63°Brix (S2), indicating differences in dissolved solids, primarily sugars, which influence sweetness, gel consistency, and shelf stability by reducing water activity. This aligns with findings by Chalchisa et al. [27], who observed increased TSS in pineapple jams with higher sugar and pectin content. Additionally, Awad et al. [34] reported TSS values ranging from 50.86% to 47.22% in pumpkin jams, highlighting the impact of formulation on TSS levels. pH values varied from 5.01 (S3) to 5.39 (S1), indicating slightly acidic conditions favorable for pectin gelation, flavor balance, and microbial safety. The lower pH in S3 may result from higher organic acid content in *Cucurbita moschata*, consistent with observations by Benmeziane-Derradji et al. [26], who noted a decrease in pH from 4.43 to 4.28 in pumpkin jam fortified with honey. Total sugar content ranged from 78.07 g/100 g (S1) to 82.52 g/100 g (S2), reflecting formulation differences and concentration effects during processing. Higher sugar levels enhance sweetness, preservation, and osmotic balance, aligning with previous findings by Makki et al. [33], who reported increased sugar content in date–pumpkin jams as sugar concentration rose. Additionally, Aljahani [35] reported total sugar content of 75.5% in pumpkin jam, emphasizing the role of formulation in sugar content. Energy values, primarily derived from carbohydrates, varied from 256.95 kcal (S1) to 270.33 kcal (S3), with samples containing higher carbohydrate and sugar fractions exhibiting greater caloric content. This confirms the strong correlation between carbohydrate concentration and energy density in fruit-based preserves. Furthermore, Aljahani et al., [35] reported an energy content of 295.5 kcal/100 g in pumpkin jam, highlighting the influence of ingredient composition on the energy content of the final product. Collectively, these findings underscore the significant impact of formulation and processing conditions on the physicochemical properties of pumpkin jam, affecting sweetness, texture, nutritional value, and shelf stability. The variations observed align with trends reported in similar fruit preserves, emphasizing the need for careful consideration of ingredient selection and processing techniques to optimize the quality of pumpkin-based jams.

The physicochemical features of pumpkin jam samples, total soluble solids (TSS), pH, total sugar and energy values in each formulation presented statistically different results ($p \leq 0.05$). TSS varied between 67.47°Brix (S1) and 69.63°Brix (S2), reflecting differences in TSS, mainly comprised of sugars that determine the degree of sweetness, gel consistency and shelf life due to lower water activity. It is in agreement with the report of Chalchisa and others [27], who found higher TSS in pineapple jams with more sugar and pectin. Additionally, Awad et al. [34] observed TSS in pumpkin jams between 50.86% and 47.22%, showing the influence of composition on TSS concentrations. pH levels ranged from 5.01 (S3) to 5.39 (S1), thus slightly acidic values suitable for pectin gelation, flavor equilibrium, and microbial stability. This lower pH value in S3, compared to the other samples, can be explained to higher content of organic acids in Cucurbita moschata according to Benmeziane-Derradji et al. [26] that showed a pH reduction from 4.43 to 4.28 of pumpkin jam with honey addition. The total sugar content varies between 78.07 g/100 g (S1) and 82.52 g/100 g (S2), which is associated with formulation differences and effects of concentration in the process. Increased sugar contents make the fruits sweeter, allow them to be packed in dry condition and help maintain osmotic equilibrium, which is in agreement with reports of Makki et al. [33], who found that the level of sugar increased in date pumpkin jams with the sugar concentration increase. Furthermore, total sugar content of 75.5% was also recorded in pumpkin jam according to Aljahani et al. [35], demonstrating contribution of formulation to sugar. Sample energy content, mainly supplied by carbohydrates ranged from 256.95 kcal (S1) to 270.33 kcal (S3), those samples with an increased contribution of carbohydrate and sugar fractions showed higher caloric value. Aljahani et al. [35] found 295.5 kcal/100 g of energy in pumpkin jam, demonstrating how a different ingredient composition can influence the energy value of the product. Taken together, all these results highlight the importance of the formulation and process on pasted pumpkin jam physicochemical characteristics (sweetness, texture, nutritional losses and shelf life). Differences ridden by the product processed fit with results in comparable fruit preserves, underlining selection and treatment of the ingredient as well processing even practice among processes to be optimized quality of pumpkin jams.

Bioactive compounds and antioxidant activity

Phenolic compounds are a major class of bioactive compounds in fruits and vegetables, recognized for their strong antioxidant activity and associated health benefits, including anti-inflammatory, cardioprotective, and anticancer effects (Tsao, 2010). In the present study, S1 (Cucurbita pepo) exhibited the highest phenolic content (21.26 g/g of gallic acid), followed by S2 (Cucurbita maxima, 18.74 g/g) and S3 (Cucurbita moschata, 15.85 g/g). These results indicate that the phenolic content is strongly influenced by pumpkin variety. The higher levels observed in S1 may be attributed to genetic factors, differences in the composition of the fruit pulp, or variations in bioactive compound biosynthesis pathways. Comparing with previous studies, Stryjecka et al. [36] reported significant variability in polyphenol content among different pumpkin species, emphasizing the influence of genotype. Similarly, Pinna et al. [37] highlighted that pumpkin pulp is a rich source of phenolics, which can be enhanced through selection of specific cultivars. Phenolic compounds not only contribute to the antioxidant activity of pumpkin products but also improve shelf life by preventing oxidative degradation. The presence of high phenolic content in pumpkin jam is therefore critical for both nutritional quality and functional properties, including free radical scavenging and prevention of oxidative stress-related diseases.

Flavonoids are a subclass of polyphenolic compounds widely recognized for their antioxidant, anti-inflammatory, and immunomodulatory effects. In this study, the flavonoid content was relatively uniform across the three pumpkin jam varieties, ranging from approximately 82–83 µg/g, with no significant differences observed. This suggests that, unlike total phenolics, flavonoid accumulation may be less affected by varietal differences and more influenced by environmental conditions, harvest time, or post-harvest handling. These findings are consistent with Stryjecka et al. [36], who reported that flavonoid levels in pumpkin pulp exhibited less variation than total phenolics. Additionally, Wafa [38] observed substantial flavonoid content in both pumpkin fruit and leaves, indicating that these compounds are consistently present and contribute to the overall antioxidant potential. Although the variation among varieties is small, flavonoids play a critical role in synergistically enhancing antioxidant activity, stabilizing other bioactive compounds, and providing health-promoting effects such as reducing oxidative stress and inflammation. Their presence in pumpkin jam thus supports both the functional quality and the nutritional value of the product.

Analysis of DPPH radical scavenging activity revealed that S3 had the highest value (184.14 µmol Eq/g), indicating superior antioxidant potential compared to S2 (118.62 µmol Eq/g) and S1 (110.57 µmol Eq/g). Interestingly, this trend did not correspond directly with the phenolic content, as S3 had the lowest phenolic concentration among the varieties. This suggests that other bioactive compounds, such as carotenoids, vitamins, or synergistic interactions among compounds, may contribute significantly to the overall antioxidant capacity. Similar findings were reported by Zdunić et al. [39], who observed that pumpkin jams retained high antioxidant activity due to the preservation of carotenoids and other bioactive compounds during processing. These results highlight the complex relationship between individual bioactive components and the total antioxidant potential in pumpkin-based products, emphasizing that antioxidant activity cannot be predicted solely from phenolic or flavonoid content.

β-Carotene is a provitamin A compound and a potent antioxidant that plays a crucial role in vision, immune function, and protection against oxidative stress. In the present study, S2 (Cucurbita maxima) exhibited the highest β-carotene content at 4.46 mg/100 g, followed by S3 (Cucurbita moschata) at 4.10 mg/100 g, and S1 (Cucurbita pepo) at 3.75 mg/100 g. These results are consistent with Stryjecka et al. [36], who reported that C. maxima contained higher levels of L-ascorbic acid and vitamin E, which may correlate with carotenoid accumulation. Similar trends have been observed in other studies: Barboza et al. [40] found β-carotene in C. maxima ranging from 13.75 to 48.88 µg/g, Zahra et al. [41] reported higher β-carotene in C. maxima compared to C. pepo, and Azhari and Rahmawaty [42] demonstrated that β-carotene content in C. moschata can vary depending on processing methods. The elevated β-carotene content in S2 underscores its nutritional significance, as this compound not only contributes to the vibrant orange color of pumpkin products but also serves as an essential nutrient supporting vision, skin health, and antioxidant defense, making C. maxima a valuable raw material for functional and health-promoting food products.

Table 4. Bioactive compounds and antioxidant activity

Parameters	S1 *(Cucurbita pepo)*	S2 *(Cucurbita maxima)*	S3 *(Cucurbita moschata)*
Phenolic content (g GAE/g)	21.26 ± 0.62[a]	18.74 ± 0.62[b]	15.85 ± 0.62[c]
Flavonoid content (µg/g)	82.66 ± 0.61[a]	83.20 ± 0.35[a]	82.83 ± 0.31[a]
DPPH radical scavenging activity (µmol Eq/g)	110.57 ± 0.83[a]	118.62 ± 0.82[a]	184.14 ± 0.82[a]
β-Carotene (mg/100 g)	3.75 ± 0.16[a]	4.46 ± 0.12[a]	4.10 ± 0.16[b]

Values are expressed as mean ± standard deviation (n = 3). Different superscript letters within the same row indicate significant differences ($p \leq 0.05$) among samples.

Sensory Evaluation

Color

Color is among the initial characteristics noticed by consumers and significantly affects product attractiveness. In this study, there were no notable differences found among the three pumpkin types, with color ratings varying from 7.27 (C. pepo) to 7.50 (C. maxima), suggesting that all samples produced visually acceptable jams. These results align with earlier studies indicating that jams made from pumpkin typically display consistent and attractive colors owing to their carotenoid levels, regardless of species or processing methods. Azevedo-Meleiro and Rodriguez-Amaya [43] noted that C. moschata, C. maxima, and C. pepo possess unique carotenoid profiles, yet color variations in processed items like jams are usually minor and not easily recognized by evaluators. Correspondingly, Awad et al. [34] observed no notable differences in color scores among pumpkin jams from various varieties, confirming the present finding that all samples retained acceptable visual quality.

Flavor

Flavor assessment showed that C. moschata jam (7.43) was slightly preferred over C. maxima (7.33) and C. pepo (7.10), indicating minor differences in panelist views. This pattern aligns with prior studies suggesting that the increased sugar levels and more intricate volatile compound profile of C. moschata enhance flavor and overall appeal [44] Minor variations in inherent qualities, such as sweetness and fragrance intensity, appear to influence consumer preferences, highlighting the importance of species selection in jam production

Texture

Texture, such as mouthfeel, spreadability, and consistency, was evaluated in pumpkin jams from three distinct varieties. The results indicated no significant differences among the samples, with scores ranging from 6.75 (C. maxima) to 7.07 (C. moschata), implying satisfactory uniformity across all varieties. This aligns with the findings of Saleem et al. [24], who reported that pumpkin jams fortified with chia seeds displayed favorable texture and spreadability properties. Similarly, Awad and Shokry et al. [34] observed that pumpkin jam exhibited good sensory acceptability, especially in terms of texture, with no significant differences among treatments. hese investigations support the current results, indicating that the texture qualities of pumpkin jams are typically stable and well-received by consumers.

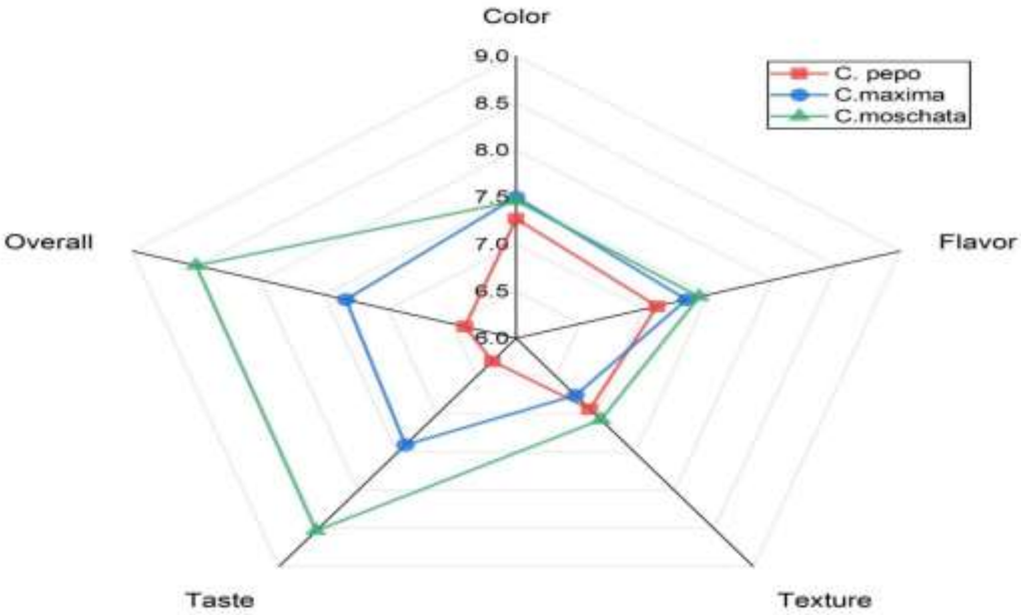
Taste

Taste is the most critical determinant of consumer acceptance. Unlike other attributes, taste showed significant variation among the samples. C. moschata received the highest score (8.53), indicating strong preference by the panelists, while C. maxima scored moderately (7.40), and C. pepo received the lowest score

(6.30). These results clearly highlight the superior palatability of C. moschata jam compared to the other two varieties. Similar trends were reported in recent studies, where pumpkin jams with higher natural sugars and smoother texture showed superior sensory scores [26][29].

Overall Acceptability

Overall acceptability reflects the combined judgment of all sensory attributes. The results showed significant differences among the samples. C. moschata achieved the highest overall score (8.50), followed by C. maxima (7.33), whereas C. pepo scored the lowest (6.40). This demonstrates that the jam prepared from C. moschata was the most liked and preferred variety among the three. Our results are consistent with Awad and Shokry's [34] evaluation of pumpkin jam's sensory qualities, where high sensory scores were observed for both the control and alternative treatments, with overall acceptability scores between 8.5 and 8.9 on a 9-point hedonic scale.



4-Conclusion

Pumpkin is a wholesome vegetable crop, rich in nutrients but largely underutilized. Despite its high nutritional value, it is predominantly consumed in its fresh form, limiting its potential applications in value-added food products. Pumpkin is recognized for its high content of antioxidants, β-carotene, and other bioactive compounds, which contribute to its health-promoting properties, such as reducing oxidative stress, supporting immune function, and preventing vitamin A deficiency. The findings of this study indicate that pumpkin can be effectively used in the development of value-added products, such as pumpkin jam, which demonstrated excellent sensory acceptability, desirable texture, and favorable nutritional quality. The addition of orange juice not only enhanced the visual appeal and color intensity of the jam but also contributed positively to the overall sensory experience, suggesting that natural fruit additives can improve both aesthetic and organoleptic properties of pumpkin-based products. Moreover, the study revealed significant differences in the nutritional composition among the pumpkin varieties tested. *Cucurbita moschata* emerged as the variety with superior nutritional characteristics, including higher carbohydrate content, dietary fiber, energy, and β-carotene levels compared to the other varieties. These differences highlight the importance of varietal selection for both nutritional quality and consumer acceptability in processed pumpkin products. These results underscore the potential of promoting pumpkin processing and diversification, which could increase the utilization of this nutritious vegetable, reduce post-harvest losses, and provide opportunities for value addition in the food industry.

Conflict of interest

The authors have no conflicts of interest to disclose that are compatible with the subject matter of this article.

Consent to participate

All authors have expressed their authorization to engage in this publication.

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Ethical Statement

Except for sensory evaluation, we have not conducted any human or animal investigations during this study. Regarding the sensory case.

Author Contribution

Md. Abdul Halim: Formal analysis, Investigation, Methodology, Software, writing – original draft, Writing – review & editing. **Md. Ripon Ali:** Formal analysis, Methodology, Software, writing – original draft, **Shishir Kumar Sarker:** Software, writing – original draft, Writing – review & editing, **Zarin Tanim Rim:** Writing – review & editing. **Fahriha Nur A Kabir:** Writing – review & editing, **Md Shohel Rana Palleb:** Writing – review & editing, **Md. Abdul Momin Sheikh:**Writing – review & editing and Resources, and **Anwara Akter Khatun:** Conceptualization, Investigation, Resources, Supervision, Writing – review & editing.

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چکیده

در این مطالعه، گونه‌های پدیوکوکوس و بیفیدوباکتریوم ایزوله‌شده در آزمایشگاه، اسید استیک را از عسل و آب‌میوه غنی از مواد مغذی تولید کردند. بیفیدوباکتریوم عملکرد بهتری نسبت به پدیوکوکوس (۵۲.۰۸ میلی‌گرم در لیتر) داشت. گوشت گوسفند غنی‌شده با اسید استیک پس از ۱۸ هفته، معیارهای بهبود یافته‌ای را نشان داد (TBA: 0.13 میلی‌گرم در کیلوگرم، P.V: 1.96 میلی‌اکی‌والان در کیلوگرم). کلستریدیوم پرفرنژنس وجود نداشت، در حالی که گونه‌های فلاوباکتریوم شناسایی شدند (۲۷۵۰ سلول در گرم). ارزیابی حسی متخصصان، امتیاز ۹۳ از ۱۰۰ را نشان داد که نشان‌دهنده مقبولیت بالا است. افزودن اسید استیک، ماندگاری در یخچال را افزایش داد و به مسائل مربوط به نگهداری در دمای غیر استاندارد پرداخت و کیفیت گوشت و مشخصات تغذیه‌ای آن را بهبود بخشید. بر اساس این اصل، هدف این مطالعه دستیابی به اهدافی با ارزش علمی و عملی و تأثیر مثبت بر سلامت محصول و در نتیجه سلامت انسان بود. بر اساس این اصل، هدف این مطالعه استفاده از یکی از اسیدهای آلی سالم است که نقش برجسته و مؤثری در حفظ مواد غذایی مانند گوشت گوسفند و نگهداری آن برای مدت طولانی در دماهای مختلف و همچنین بهبود کیفیت و ویژگی‌های حسی آن مانند طعم، رنگ، بافت و بو دارد.