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Research Article

Quality Jam from Baobab (*Adansonia digitata* L) Fruit Pulp Powder: Formulation and Evaluation of Its Physicochemical and Nutritional Properties

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Adansonia digitata L (Baobab) is a large plant species which thrives in many semiarid regions of the world with remarkable economic and nutritional importance. In Ethiopia, it grows in deserts and hot lowlands. Industrially, baobab fruit pulp (powder) is used for producing good quality jams. This study was carried out to (a) develop a formulation protocol for producing high-quality baobab jam, (b) characterize the jam using standard physicochemical, microbiological, and sensory evaluation methods, and (c) examine the effects of time and temperature of storage on the quality as well as shelf life of the jam. Out of the seven formulations tested, a formulation enriched with 55 g table sugar, 45 g baobab fruit powder, 0.50 g ascorbic acid, and 0.40 to 0.60 g citrus pectin jelling (formulation no. 6) and another one enriched with 60 g table sugar, 40 g baobab fruit powder, 0.50 g ascorbic acid, and 0.40 to 0.60 g citrus pectin jelling (formulation no. 7) resulted in the best jam products. The jam product of formulation no. 7 enriched with 0.50 g ascorbic acid and 0.60 g citrus pectin jelling was better in terms of storage stability and sensory acceptability. Increasing storage time (up to 45 to 90 days) and temperature (from 10–12°C to 25–27°C) lowered the products' nutritional quality and sensory acceptability. High-microbial growths were observed in the products stored at higher temperature longer, but all the microbial loads were far below the acceptable limit. In the absence of measures that improve their shelf lives, household and small-scale jam products have to be consumed fresh or within weeks after their preparation.

1. Introduction

Adansonia digitata L (Baobab) (Malvaceae, subfamily Bombacaceae) is a well-known, giant tree growing in semiarid regions in Africa, Malaysia, China, Jamaica, and Australia. It has remarkable economical and nutritional significance to rural communities [1–3]. In Ethiopia, the plant grows in deserts and hot lowlands [2]. Baobab is a multipurpose, locally, and globally endangered tree plant. It is medicinally an important species, widely used for producing food and nonfood products. It is highly valued in rural communities in many sub-Saharan and other arid African parts due to its wider use for animal fodder and human food [4].

Baobab fruit pulp (powder) is industrially used for producing high-quality jams. Jams are processed fruit products with a minimum of 40% sugar. They can be stored for several weeks. High-quality jams are characterized by their consistency, stability, and nutritional properties when tested fresh and after storage [5]. Thus, baobab fruit powder is used for producing high-quality jam having attractive

gelation, nutritional quality, and medicinal properties. This is because the fruit pulp powder is nutrient-rich, containing ascorbic acid, carbohydrates, minerals, crude fiber, vitamins, proteins, lipids, and other phytochemicals. The fruit has low fat, moisture, and protein contents and low pH that makes its jams stable and consistent so that it can be stored for many weeks without microbial spoilage [6–8]. Baobab is often called "the small pharmacy" or "chemist tree" [3] because its fruit is an excellent source of antioxidants with far-reaching health benefits [9, 10].

Baobab fruit pulp has been attracting the interests of food processing companies due to its excellent nutritional and health benefits as well as its high potential for industrial use for producing functional foods and drinks. Thus, the demand for the fruit has been increasing [11, 12]. But the plant is still underutilized [3]. Its local and industrial potential is not yet explored. Thus, scientific studies towards its conservation and sustainable use are timely. Based on these justifications, the present research was aimed to realize the following objectives, namely, (a) investigating physicochemical features, proximate compositions, mineral contents, and microbial characteristics of baobab fruit pulp powder, (b) devising a formulation and preparation protocols of good quality baobab jam, (c) establishing the characteristics of high-quality baobab jam products, and (d) examining how time and temperature storage affect the physicochemical features, proximate compositions, mineral contents, microbial features, and sensory properties of the jams. The findings of the study are important to assist local people in using the fruit as nutritional supplements and entrepreneurs in starting businesses on baobab jam production and distribution. Moreover, individuals interested in making fruit jam for household consumption are provided with an easy formulation method. Researchers are also supplied with useful data for conducting future research studies on conservation and sustainable use of the tree species.

2. Methods and Materials

2.1. Collection Site of Baobab Fruits. The baobab fruits used in the research were collected from Tekeze Valley (11° 40′ and 15° 12′ N and 36° 30′ and 39° 50′ E), Western Zone of Tigrai Regional State, Ethiopia. The site of fruit collection is located 96 km southwest of Endaselassie city, stretching between Asgede-Tsimbla district to the east and Wolqait district to the west [13].

2.2. Collection and Preparation of Fruit Samples. Fruit collection was carried out during the fruit ripening season of December 2019. Healthy, ripened, and brownish fruits were carefully collected from five purposively selected mature trees. The fruits collected from each tree were counted and recorded. Then, they were packed in plastic bags and shipped to the micropropagation facility at Tigrai Biotechnology Centre PLC and geochemical laboratory at the Natural and Computational Sciences College, Mekelle University, Mekelle, Ethiopia, and stored in dry storage boxes at room temperature until processed. Ingredients used to formulate baobab jam, namely, sugar, food-grade pectin, and ascorbic acid were procured from local market as well as chemical venders in Mekelle city. Healthy and dry fruits with no discoloration were selected and prepared for processing by washing with warm tap water and detergent to remove soil, debris, and microbial contaminants (Figure 1). Washed fruits were immediately placed into a laminar air flow (LAF) cabinet and allowed to fully dry [7].

2.3. Sterilization of Containers. Equipment, glassware, and plastic containers used for formulating and preparing jams were enclosed with aluminum foil and autoclaved for 20 min at 15 psi and 121°C [14]. All sterilized items were immediately put in aseptic conditions until used for processing and packaging.

2.4. Separation of Powder of the Fruits. The baobab woody fruit shells were removed with sterilized stainless steel knives inside LAF. The white baobab fruit powder holds several seeds and fibers as a matrix. The powder was then separated from the seeds and fibers by smashing the mass with pestle and collected into clean and sterilized mica bowl. The powder was sieved using 0.9 mm pore mesh. Fine and pure powder was put into clean and sterilized jars. The jars were, then, tightly capped and stored in a dark, cool place until used for jam formulation and further analyses [7].

2.5. Proximate Analyses. Proximate compositions of the baobab fruit pulp powder and different jam formulations were assessed according to the methods established by the Association of Analytical Chemists (925.05) (AOAC) [15] as well as other pertinent and well-established methods [16–19].

2.5.1. Moisture Content Investigation. Determination of the samples' moisture contents was carried out by the oven-drying method [15, 16]. An empty watch glass was oven-dried at 105°C for 3.0 hrs, transferred to a desiccator to cool, and weighed. A 3.0 g sample was put onto the watch glass (W_1) and oven-dried for 3.0 hrs at 105°C. After drying, the glass with its contents was transferred to a desiccator to cool and was reweighed (W_2). The percentage of moisture contents of the samples was computed as follows: $\%\,\text{Moisture Content} = [(W_1 - W_2) \div (W_1)] \times 100$, whereby W_1 refers to the original sample's weight, while W_2 refers to the sample's weight after it was dried.

2.5.2. Ash Content Investigation. Porcelain crucible was prepared by cleaning, heating at 100°C, cooling, and weighing (W_C). A 5.0 g sample (W_S) was placed onto porcelain crucible (W_{C+S}) and heated in oven at a temperature of 550°C overnight, allowed to cool in a desiccator, and weighed (W_{C+A}). The ash content (in percentage) was computed as follows: $\%\text{Ash} = [[(W_{C+A}) - (W_C)] \div [(W_{C+S}) - (W_C)]] \times 100$, where W_C stands for crucible's weight, W_A stands for ash's weight, and W_S stands for sample's weight [15].

2.5.3. Total Fat Determination. The manual extraction method was employed in analyzing crude content of fat [17]. A 2.0 g of sample (W_1) was added to a 250 mL Erlenmeyer

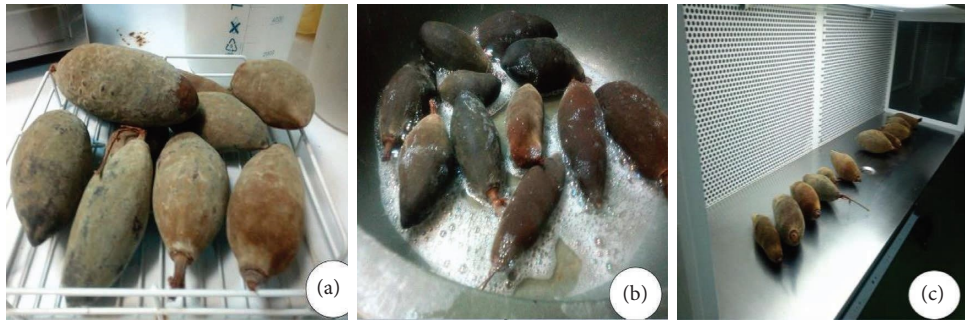

Figure 1: Washing baobab fruit. (a) Unwashed; (b) washing; (c) washed and drying.

flask, and a 2.0 mL of alcohol was put to the flask. The content was moistened by stirring and mixed thoroughly with a 10.0 mL dil. 4N HCl. The Erlenmeyer flask was placed on a heater, refluxed for 30 minutes, and stirred frequently to hydrolyze the sample completely. Then, 10.0 mL of ethyl alcohol was put to the content and left to cool. The flask was washed, and the content was transferred to an extraction tube holding a 25.0 mL of diethyl ether in three portions. The extraction tube was capped using a cork and was shaken forcefully for one minute. After that, 25.0 mL of petroleum ether was put to the tube of extraction and shaken strongly for one minute until the liquid appeared clear at its upper portion. The solution of ether plus fat was filtered using a funnel tightly closed with a piece of cotton at its extended end. The ether-fat solution was, then, left to let the ether pass into the flask. The Erlenmeyer flask was allowed to oven-dry at a temperature of 100°C and to cool in a desiccator. Then, the flask was weighed (W_2), and its weight was recorded. Liquid sample extraction was carried out two times in the extraction tube with the same solvent. The distinctive solutions of ether were transferred into the same flask via the funnel. The solvents were completely evaporated on a water bath at 70–80°C. Then, the fat was allowed to oven dry at a temperature of 105°C till an invariable weight was attained. At the end, the flask was desiccated and weighed (W_3), and the weight was recorded. The content of crude fat was computed as follows: $\%\,\text{Crude Fat} = [(W_3 - W_2) \div (W_1)] \times 100$, wherein W_1 represents sample's weight, W_2 represents dry flask's weight before the extraction process, and W_3 represents flask's weight after being dried by the process of extraction.

2.5.4. Fiber Content Determination. Determination of fiber content was conducted as per the procedure of the Official Methods of Analysis of the AOAC [18]. A 2.0 g of sample (W_1) was put into a round-bottom flask. After that, 100.0 mL solution of 0.023M H_2SO_4 was transferred into the flask and the content was boiled for 30 minutes under reflux. The boiled solution was immediately filtered out from the nonsoluble material, rinsed using nonacidic hot water, and put into a cone-shaped flask. A 100 mL hot solution of 0.312M NaOH was put to it. Then, the content was allowed to boil for 30 minutes under a reflux and filtered immediately. The resulting residue was thus weighed, rinsed with a solution of acetone, placed into crucible, oven-dried to the same weight, allowed to cool in a lab bench desiccator, and finally weighed with its crucible, yielding W_2. The cooled crucible holding the content was cremated at 555°C for 2.0 hrs in a muffle oven, let to cool in a desiccator, and finally weighed again to obtain W_3. Thus, the content of crude fiber was calculated as follows: $\%\,\text{Crude Fiber Content} = [(W_2 - W_3) \div (W_1)] \times 100$, with W_1, W_2, and W_3, representing the weights of the sample, insoluble material, and ash, respectively.

2.5.5. Crude Protein Content Determination. The determination of the content of crude protein was conducted by the UV-vis spectrophotometer procedure given in the work of Kruis [19]. Total nitrogen determination was conducted by transferring 0.40 g of sample to a digestion bomb. After that, a 3.0 mL H_2O_2 and a 2.50 mL digestion mixture (containing sulfuric and salicylic acids plus selenium) were put into the bomb, and the mixed content was allowed to heat at 100°C for 12 hrs inside a dry stove and cooled. The cooled content was then diluted using 15.0 mL of distilled water and immediately filtered with a filter paper to a 50.0 mL round-bottom flask. At the end, n1 and n2 powders of nitrogen were added and homogenized for about 10 minutes. The total amount of nitrogen was recorded from the reading of the UV-vis spectrophotometer. The content of crude protein was computed as follows: % Crude Protein Content = Total Nitrogen (in mg/100 g) × 6.25 (Conversion Factor).

2.5.6. Total Carbohydrate Content Investigation. Assessments of total carbohydrate were carried out via the methodology of exclusion. The methods yield total carbohydrate content (%) by subtracting the contents of the sum of the constituents of proximate analysis from 100%. The content was computed as follows: % Total Carbohydrate Content = 100 − (Sum of Percentages of Moisture + Ash + Crude Fat + Crude Fiber + Crude Protein Contents) [15].

2.5.7. Gross Energy Determination. Determination of the values of the samples' gross energy (kcal/100 g) was carried out by adding the summation of the contents of crude protein plus total carbohydrate multiplied with 4.0 and the crude fat content multiplied with 9.0 (Value of

Gross Energy (kcal/100 g) = [(% Crude Protein Content + % Total Carbohydrate Content) × 4.0] + [(% Crude Fat Content) × 9.0]) [15].

2.6. Physicochemical Analyses. Physicochemical analyses were carried out to determine the following: (a) pH, (b) total titratable acidity (i.e., TTA), and (c) total soluble solute (i.e., TSS) of samples of baobab pulp power and jam products. (1) Determination of pH of a sample was conducted by taking 10 g sample, mixing it to 100.0 mL of distilled water in a glass beaker, homogenizing the content through stirring for 5.0 minutes, and measuring its pH value. The pH meter was carefully calibrated to 7.0 using a buffering solution. (2) Determination of TTA was conducted according to the method described in the works of Lefebvre and Al (2002) [20]. It was established by taking 10.0 mL of sample, mixing the content into 10.0 mL of distilled water, putting 2-3 drops of a phenolphthalein indicator, and titrating the solution against a 0.1N solution of NaOH till the solution changed its color to pink. The TTA was computed as follows: Total Titratable Acidity (%) = [Titrant × Ascorbic Acid Equivalent Weight × 100] ÷ [Sample's Volume × 1,000]. (3) Determination of the TTS level (in °Brix) of a sample was carried out using a lab bench digital refractometer (ATAGO 0–80%). A sample was equilibrated at 20°C before the measurement was taken. A 1.0 mL sample was then placed onto a prism of refractometer, and a reading was taken after 20–25 sec.

2.7. Minerals' Analyses. Mineral analyses of samples were conducted as per the procedure established by Kruis (2014) [19]. The method involved sample digestion, calibration of standard concentrations, and determination of the mineral contents. For Mg, Ca, Zn, Cu, Fe, Na, and K determination, sample digestion was conducted by taking 5 g sample into a conical flask, adding 20 mL aqua raja and 3 mL H_2O_2, heating the content on hot plate for 30 min, adding 20 mL 0.1N HCl, and stirring it to facilitate the digestion process. Then, the solution was cooled, filtered by the use of the standard filter paper to a 50.0 mL beaker, and kept until analyses. For N and P determination, sample digestion was conducted by placing 0.40 g of sample in a digesting bomb, adding 3.0 mL of H_2O_2 and 2.5 mL of digestion mixture (containing sulfuric and salicylic acids plus selenium), and heating the content at 100°C in a dry stove for 12 hrs. Then, the digested solution was diluted using 15.0 mL of distilled water and filtered to a 50.0 mL glass beaker. At the end, nitrogen powders of n1 and n2 were put and the solution was thoroughly mixed by stirring for 10 minutes and prepared for N determination using a UV-vis spectrophotometer. Determination of the minerals was carried out by calibrating the instruments using the standard solutions (Table 1). Determination of Mg, Ca, Zn, Cu, and Fe contents (mg/L) were carried out with atomic absorption spectrometer (Model VARIANN). Determination of the contents of Na and K (mg/L) was carried out by the use of the flame photometer (Model JENWAY). Finally, determination of the contents of N and P (mg/L) was carried out by using a UV-vis spectrophotometer.

Table 1: Calibration standard for analyses of minerals.

Standard	Calibration of standard concentrations (ppm)								
	Mg	Ca	Zn	Fe	Cu	Na	K	P	N
0	0	0	0	0	0	0	0	0	0
1	5	5	2	5	2	2	2	0.5	2
2	10	10	5	10	5	5	5	1	5
3	20	20	—	20	10	10	10	1.5	10
4	50	50	—	—	—	—	—	—	—

2.8. Determination of Formulation Protocol for Producing the Best Jam. Formulation of the best jam was carried out using a 2-step procedure. Procedure 1 was performed to decide the best combination of baobab powder and sugar to produce the best jam. Hence, seven products were prepared using seven formulation combinations of baobab powder and white crystal sugar with constant amount of ascorbic acid and water (Table 2). Then, the best jam products were selected based on their TSS contents. Once the best jam formulations were determined, the jam product with the best jellying property was identified using Procedure 2. To this end, 0.20 to 0.80 g citrus pectin was added to the best jam products as a jelling agent. The jelly jam products were subjected to physical, chemical, nutritional, and microbial analyses and sensory evaluation.

2.8.1. Preparation of Baobab Jam and Determining the Best Formulations. Baobab jam was prepared according to the methods described in publications of the Food and Agriculture Organization (2009) [21] and Pare and Mandhyan (2011) [22] (Procedure 1). The content containing baobab powder, sugar, and distilled water was boiled in sterile, stainless steel food cooker. After 2 to 3 min of boiling, a thermometer was placed in it and further boiled until the reading of the thermometer reached 70 to 74°C. Then, ascorbic acid was added at that temperature, and pH and TSS of the content were subsequently measured using a digital pH meter and digital refractometer. The content was further boiled to 105°C by continuously stirring to produce a jam. The temperature of the jam was maintained for 2 min, and pH and TSS measurements were performed again. This process yielded formulations no. 6 and no. 7 as the best jam ready for jelling using appropriate amounts of citrus pectin.

2.8.2. Jellying of Baobab Jam and Selecting the Best Jelly Jam. Baobab jam jellying was performed by boiling the contents in formulations no. 6 and no. 7 in a sterile, stainless steel food cooker (Procedure 2). The content was boiled to about 40°C, and pectin was added. The content was maintained at 40°C for 2 to 3 min to allow proper pectin hydration. Then, it was boiled to 70 to 74°C, and ascorbic acid was added; the first pH and TSS measurements were performed. The content was further boiled to 105°C while being continuously stirred to produce jelly jam. The second pH and TSS measurements were carried out, and the final product was cooled at 90°C within LAF and hot-bottled in sterile glass jars. The bottled products were cooled and stored in a cool and secure place.

Table 2: Best baobab jam formulation.

Formulations	(a) Jam making (procedure 1)				(b) Jelling (procedure 2)			
	Powder (g)	Sugar (g)	Ascorbic acid (g)	Water (mL)	Citrus pectin (g)			
1	100	0	0.5	200	—	—	—	—
2	75	25	0.5	200	—	—	—	—
3	65	35	0.5	200	—	—	—	—
4	55	45	0.5	200	—	—	—	—
5	50	50	0.5	200	—	—	—	—
6	45	55	0.5	200	0.2	0.4	0.6	0.8
7	40	60	0.5	200	0.2	0.4	0.6	0.8

2.8.3. Analysis of the Jellying Property of the Baobab Jam. Consistency of the jam products was analyzed using an industry standard test called the spoon test [22]. It comprised two tests. The first test was conducted for assessing if a sample of jam placed on a spoon remains as a droplet or spreads flatly. The second test was carried out for establishing the time for the jam to drop from an inclined spoon.

2.9. Examining the Effects of Storage Time and Temperature. Fresh and stored baobab jam products prepared according to the two formulation protocols were examined using physicochemical and microbial analyses and sensory evaluation methods, whereas the fresh jam products were examined within five days, and the stored products were examined after 30 to 90 days. The effects of storage temperature were also studied. For this purpose, the products were stored in dark, sterile rooms set at a low storage temperature (LST) of 10–12°C and high storage temperature (HST) of 25–27°C in the laboratory facility at Tigrai Biotechnology Centre PLC. The temperatures of the storage rooms were measured three times a day using a digital thermohygrometer throughout the study period. The tests and observations were performed to examine the quality of the products (i.e., symptom of spoilage, instability, change in color, smell, and flavor), physicochemical properties (i.e., pH, TTA, and TSS), and proximate analysis (moisture and ash content). Laboratory tests were performed at the Organic Chemistry Laboratory of the College of Natural and Computational Sciences, Mekelle University.

2.10. Analysis of Microbial Load of Baobab Powder and Jam Products. Analyses of microbial qualities of baobab powder and jam products were carried out according to the standard methods of food microbiology [23]. First, solutions that were serially diluted to 10^{-5} were prepared from samples of the powder and jam products. Then, tests to determine the microbial quality of the samples were performed using the serially diluted solutions. (1) Total aerobic bacteria were determined by taking 1.0 mL serially diluted sample using discrete pipette and inoculating the sample onto sterile nutrient agar plates. The agar plates were inverted and incubated at a temperature of 37°C for 24.0 hrs. Bacterial growth was inspected after 2-3 days, and the colonies were counted. (2) Assessment of the total coliform was conducted by taking 1.0 mL of the sample and plating it in duplicates on selective and general growth media plates (i.e., MacConkey agar, MacConkey broth, EBM agar, and Salmonella and Shigella agar). The media plates were inverted and incubated at a temperature of 37°C for 48–72 hrs, growth of coliforms was inspected starting day 2, and any number of colonies was counted. (3) Determination of load of yeast and molds was carried out by taking 1.0 mL of sample and plating it onto potato dextrose agar (PDA) plates. The plates were inverted and allowed to incubate at 27°C for 3–5 days. Inspection of growths of yeast and mold were conducted after 72 hrs, and plates with no yeast and mold were incubated for additional 48 hrs to complete the standard incubation period. In all cases, colonies were counted by the use of a digital colony counter and the counts were denoted as colony forming units per gram (CFU/g).

2.11. Evaluation of Sensory Qualities of the Formulated Jams. On evaluation of sensory qualities, the baobab jams varied in their formulation, storage temperature, and storage time, which were performed based on a 7-point Hedonic scale [24]. It was carried out by an evaluation panel of 30 persons (20 females, 10 males; aged 24–33 years) who were selected purposefully from the employees of Tigrai Biotechnology Centre PLC laboratory, Mekelle city. Members of the evaluation panel were 2 masters' degree holders, 8 bachelors' degree holders, 12 postsecondary diploma holders, 3 grade 12 certificate holders, and 5 grade 10 certificate holders. They were trained on how to perform the evaluation and the terminologies and scales used in the evaluation process. The assessments of the jam formulations were performed using seven quality scales, such as color, texture, aroma, flavour, mouth feel (viscosity), overall appearance, and overall liking. According to this scale, "7" represents "like very much," "6" represents like moderately, "5" represents "like slightly," "4" represents "neither like nor dislike," "3" represents "dislike slightly," "2" represents "dislike moderately," and "1" represents "dislike very much." The sensory qualities of the two jam products were evaluated on days 1, 45, and 90. On day 1, sensory evaluations were performed with fresh products stored at room (ambient) temperature. On days 45 and 90, the evaluations were carried out with products at the two-storage temperatures.

2.12. Collection and Analyses of Data. Quantitative data were gathered from various measures, counts, tests, and experiments in triplicates and processed with pertinent descriptive and inferential statistics with the use of SPSS Ver. 20. All data

were processed by analysis of variance (ANOVA) at pre-established ≤0.05 p value. Post-ANOVA mean (±SD) comparisons were performed based on the least significance difference. The qualitative data acquired through visual observations as well as using the microscope were also employed to support the findings of quantitative data processing.

3. Results and Discussion

3.1. Fruiting Capacity of the Baobab Tree of Tekeze Valley. Tekeze Valley is very rich in baobab plant. But there are no efforts towards its conservation and sustainable use. There is no traditional or modern processing technology or system in the valley and elsewhere in Ethiopia that exploit the fruit for domestic/household or industrial use. Therefore, no scientific inquiry was so far attempted to investigate the fruiting capacity of the plant. The present study has made a preliminary assessment on the fruiting volumes of the trees in relation to their sizes. Fifteen trees with five different size-categories were selected from the valley by means of visual observation, and their fruits were counted and compared (Table 3; Figure 2). The trees in each category were with comparable sizes. The mean fruiting capacity of the trees increased with increasing tree size, ranging from 50 to >510 with an average 331 for all sizes. Studies in Kenya [25] and the Sudan [26] have reported a higher mean number of fruits. The Kenyan study reported that a single tree can yield 12 to 2,675 (average being 360) fruits, while that of the Sudanese study reported 145 and 595 fruits per single tree (average being 381 fruits). Several factors can be accounted for the differences, but the potential for domestic and industrial processing the fruit is very high, calling for strategies towards conservation and sustainable use of this useful natural resource.

Table 3: Fruiting capacity of *A. digitata* trees in Tekeze valley.

SN	Size categories of trees	n	Mean (±DS) fruits
1	Size category 1: very small	3	49.67 ± 0.57^{e}
2	Size category 2: small	3	259.67 ± 1.53^{d}
3	Size category 3: medium sized	3	378.33 ± 0.57^{c}
4	Size category 4: large	3	457.00 ± 1.00^{b}
5	Size category 5: very large	3	511.33 ± 1.15^{a}

Means (±SD) values in a row with different superscripts signify significant difference at $p \leq 0.05$.

Figure 2: Baobab tree with its fruits and ripened baobab fruits.

3.2. Quantitative Analyses of the Baobab Fruit Powder. The fruit of baobab is covered by woody shell enclosing seeds, powder, and fibers. The fibers are attached to the shell's inside wall. Baobab powder serves as a matrix, wherein the seeds are tightly embedded. Thus, the seeds, the powder, and the fibers were separated by pestle and mortar. The amount of seeds, powder, and fiber increases with increasing the size of the fruits (Table 4). In majority of the cases, the increments were statistically significant. The proportion of the components did not show notable differences or patterns among the different sizes of the fruits. Overall, the shell, powder, and seeds of the fruit accounted for 40.6, 20.6, and 38.1% of the total biomass, respectively. One study in Malawi has reported that yielded the shell, powder, and seeds constituted 45, 15, and 40%, respectively [27, 28]. The Tekeze baobab fruits have notably higher amount of power that can encourage for its sustainable uses.

3.3. Physicochemical Properties and Proximate Composition of A. digitata Fruit Powder. Physicochemical properties and proximate composition of baobab fruit powder were studied. Examination of the physicochemical properties of the powder showed that it is very acidic with substantial proportion of TSS (Table 5). Analyses of its proximate composition has showed low mean moisture content, crude fat, and crude protein and high mean crude ash, crude fiber, and total carbohydrate content (Table 6). Higher crude fiber and total carbohydrate contents as compared to other proximate components were also reported in studies carried out in the Sudan and elsewhere [29–31]. The mean gross energy value observed in the current study was also comparable to results of other research studies that reported 202.9 to 357.3.9 kcal/100 g dry weight [31, 32]. This is due to the high total carbohydrate content.

3.4. Physicochemical Properties of A. digitata Jams. Seven jam products were prepared using seven combinations of the baobab fruit pulp powder and table sugar. Then, the products were analyzed for pH and TSS (°Brix) content to determine which ones were with the best quality in terms of pH and TSS. The mean pH and TSS content of formulation no. 1 (100% powder) were 3.15 and 19.1, respectively (Figure 3). This value was very high compared to one previous finding (11.63) [7]. In all formulations, the mean TSS has increased with increasing the proportion of sugar,

Table 4: Quantitative determination of the components of *A. digitata* fruit.

SN	Whole fruit	Mean (±SD) weight (in grams) and percentage (%) of baobab fruit components							
		Shell		Powder		Seed		Impurity	
		Weight	%	Weight	%	Weight	%	Weight	%
1	184	80.3 ± 1.5^{e}	43.5	40.0 ± 1.0^{f}	21.7	63.0 ± 0.0^{e}	34.2	1.0 ± 0.0^{b}	0.5
2	248	102.0 ± 1.0^{d}	41.1	48.0 ± 1.0^{e}	19.4	95.0 ± 1.0^{d}	38.3	1.3 ± 0.6^{ba}	0.5
3	275	115.7 ± 0.6^{c}	42.2	55.3 ± 1.2^{d}	20.0	100.3 ± 1.5^{c}	36.4	2.0 ± 0.0^{ba}	0.7
4	300	115.0 ± 1.0^{c}	38.3	61.7 ± 1.5^{c}	20.7	123.3 ± 1.5^{b}	41.0	2.0 ± 0.0^{ba}	0.7
5	368	139.3 ± 1.2^{b}	37.8	76.3 ± 1.2^{b}	20.7	149.7 ± 1.5^{a}	40.8	2.7 ± 1.2^{a}	0.7
6	400	161.7 ± 1.5^{a}	40.5	85.0 ± 1.0^{a}	21.3	151.0 ± 1.0^{a}	37.8	2.7 ± 1.2^{a}	0.7

Means (±SD) values in a row with different superscripts signify significant difference at $p \leq 0.05$.

Table 5: Physicochemical properties of *A. digitata* fruit powder.

SN	Physicochemical properties	UoM	Mean (±SD) values
1	pH	pH	3.12 ± 0.02
2	Total titratable acidity	%	1.98 ± 0.01
3	Total soluble solute	°Brix	19.15 ± 0.23

UoM: unit of measurement.

Table 6: Proximate composition of *A. digitata* fruit powder.

SN	Proximate composition	UoM	Mean (±SD) values
1	Moisture	Percentage	3.80 ± 0.03
2	Ash	»	13.36 ± 0.08
3	Crude fiber	»	6.43 ± 0.24
4	Crude fat	»	1.08 ± 0.01
5	Crude protein	»	2.15 ± 0.02
6	Total carbohydrate	»	73.18 ± 1.12
7	Gross energy	kcal/100 g	311.04 ± 2.26

UoM: unit of measurement.

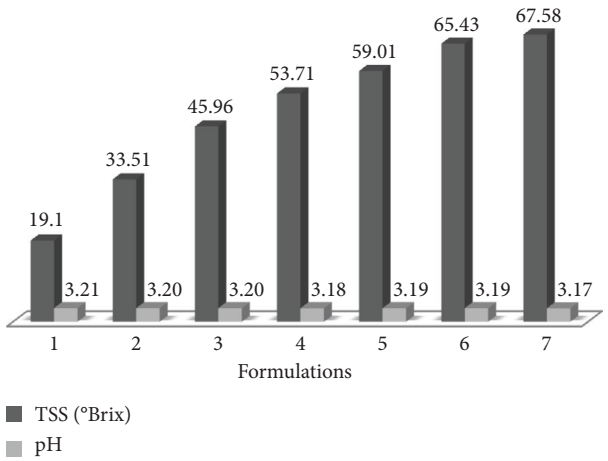

Figure 3: Mean TSS and pH values of the jams of the seven formulations.

while the mean pH was slowly decreasing. Out of the seven formulation protocols, formulations no. 6 and no. 7 yielded best jams with their mean TSS content falling within the acceptable range of 65–68°Brix [21]. The mean TSS contents of formulations no. 6 and no. 7 were 65.43 and 67.38°Brix, respectively. The powder-to-sugar ratios of formulations no. 6 and no. 7 were comparable to ratios of other researchers who formulated the best jam products. Sugar making 35 to 50% of the ingredients yields the best products [33–35].

3.5. Jellying Properties of A. digitata Jams. Based on their mean TSS contents, jam products of formulations no. 6 and no. 7 were tested for jelling at 0.20, 0.40, 0.60, and 0.80 g concentrations of citrus pectin to select the final jelled jam product. Evaluation of the jelled products using the spoon test revealed that lower pectin concentration (0.20 g) was ineffective, while higher concentration (0.80 g) caused overjelling. The evaluation also revealed that 0.40 g and 0.60 g were acceptable proportions for jelling baobab jam. One study reported 0.40 g citrus pectin as the best proportion for jelling [36].

3.6. Physicochemical Properties of Stored A. digitata Jams. Jam products prepared by using the protocols of formulations no. 6 and no. 7 were evaluated in detail. On day 5, the mean pH of the jams was statistically comparable regardless of the storage temperature, ranging from 3.14 to 3.19 and falling within the recommended limits [21] (Table 7). The reduction in pH with increasing storage time was relatively significant when the products were stored at higher temperature. But the products can be considered stable as far as pH is concerned. The mean TTA values of the two products were not affected by storage temperature and time. They remained within the acceptable range. Therefore, the jams can be stored at low and high temperatures without losing their stability and consistency. Similarly, with the exception, the jam product prepared according to formulation no. 6 and stored at the higher temperature for 90 days, products stored under all storage conditions had mean TSS contents within the acceptable range of 65–68°Brix [22]. The nearly 2.0 °Brix difference in the mean TSS between the two formulations was related to the difference in sugar content [30, 37]. The milder changes in the mean pH, TTA, and TSS of the two jam products when they were stored for up to 90 days under low- and high-storage temperatures imply that they were stable and consistent.

3.7. Proximate Composition of Stored A. digitata Jams. Moisture content has an important function in affecting shelf lives of any food products [22]. The mean moisture contents of jam products prepared using formulation no. 6

Table 7: Time and temperature of storage on the physicochemical properties *A. digitata* jam products.

Storage conditions		Mean (±SD) value of physicochemical properties		
Time (days)	Temperature (°C)	pH	TTA (%)	TSS (°Brix)
(a) Formulation no. 6				
5	10–12	3.17 ± 0.01^{ab}	$0.36 \pm 0.04^{e-h}$	65.43 ± 0.01^{c}
	25–27	$3.15 \pm 0.03^{a-c}$	$0.42 \pm 0.17^{d-f}$	65.33 ± 0.09^{c}
30	10–12	$3.14 \pm 0.01^{b-d}$	$0.39 \pm 0.01^{d-g}$	65.42 ± 0.01^{c}
	25–27	$3.12 \pm 0.02^{c-e}$	$0.40 \pm 0.02^{d-f}$	65.41 ± 0.01^{c}
60	10–12	3.11 ± 0.02^{df}	0.43 ± 0.01^{de}	65.42 ± 0.01^{c}
	25–27	3.10 ± 0.01^{d}	0.53 ± 0.02^{c}	65.27 ± 0.13^{c}
90	10–12	2.97 ± 0.00^{h}	0.67 ± 0.02^{b}	65.40 ± 0.02^{c}
	25–27	2.78 ± 0.01^{h}	0.82 ± 0.02^{a}	64.26 ± 0.34^{d}
(b) Formulation no. 7				
5	10–12	3.19 ± 0.01^{a}	0.30 ± 0.02^{h}	67.57 ± 0.01^{a}
	25–27	$3.14 \pm 0.06^{b-d}$	0.31 ± 0.03^{gh}	67.58 ± 0.02^{a}
30	10–12	3.17 ± 0.01^{ab}	$0.34 \pm 0.02^{f-h}$	67.56 ± 0.04^{a}
	25–27	$3.15 \pm 0.01^{a-c}$	$0.39 \pm 0.01^{d-g}$	67.49 ± 0.03^{a}
60	10–12	$3.14 \pm 0.01^{b-d}$	0.46 ± 0.01^{d}	67.55 ± 0.05^{a}
	25–27	3.11 ± 0.01^{de}	0.55 ± 0.04^{c}	67.43 ± 0.11^{a}
90	10–12	2.98 ± 0.02^{f}	0.69 ± 0.01^{b}	67.53 ± 0.04^{a}
	25–27	2.88 ± 0.01^{g}	0.88 ± 0.02^{a}	67.08 ± 0.06^{b}

Means (±SD) values along a given column denoted with different superscripts are significantly different at $p \leq 0.05$.

were statistically higher than those prepared using formulation no. 7, irrespective of the storage temperature and time ($p \leq 0.05$) (Table 8). This difference might be related to the proportions of the baobab pulp powder and sugar in the products rather than the storage conditions. Thus, it can be stated that both products have the capacity to maintain their moisture contents when they were stored for up to 90 days. Similar findings were reported elsewhere [7]. The slight reduction in mean moisture by day 60 and slight increment by day 90 might be due to microbial enzyme activities [38]. Increasing the sugar concentration of food products reduces their moisture contents to make them unsuitable for growth of microorganisms and improve their shelf lives [39].

Ash contents are reflections of mineral contents of food products. In both jam products, the change in mean ash contents showed the same pattern. (a) The mean ash content showed slow decrement over 90 days of storage. (b) Jam products stored at both storage temperatures had comparable mean ash contents until day 30. (c) At lower storage temperature, the products showed comparable mean ash contents until day 60. These imply that the interactions of storage time and temperature lead to the reduction of mean ash contents. The reduction in ash content is believed to be linked to the activities of microorganisms present in the jam. Some microorganisms are known to deplete minerals from foods for their own growth [30, 38].

Storage time and temperature have resulted in statistically significant changes in the two jams' mean crude fiber, crude fat, and crude protein contents. When storage temperature and time were increased, the mean values of these components decreased, whereas the reductions in the mean crude fat and protein were almost by half, and the reductions in mean crude fiber were small. The reductions were also relatively higher at higher storage temperatures. In all cases, the changes in the mean proximate components were very small. Thus, the products can be regarded as stable and consistent.

3.8. Mineral Contents of Fruit Powder and Stored A. digitata Jams. The total carbohydrate content of the baobab fruit pulp powder was greater than 73% (Table 6). Hence, the baobab jam was principally prepared as a good source of carbohydrate. Moreover, the mean mineral contents of the powder were high (Table 9). The high calcium content in baobab fruit has been considered as an excellent source of Ca for pregnant and lactating women, children, and the elderly [27]. Jam products retain 20 to 80% of the mineral contents of the fruit pulp powder. It is well established that the jam preparation process reduces mineral contents [35]. That being true, both jam products of the present study can be good sources of minerals, especially Ca, Mg, P, and the micronutrients.

The mean contents of many of the tested minerals were lower or higher than what were reported in other studies in Saudi Arabia [33] and Sudan [29]. These variations may be because of environmental factors such as soil properties and other ecological factors. Since baobab grows in different agroecologies and soil conditions in Tigrai, Ethiopia, further research is required to explore the mineral contents of fruits harvested from various agroecologies and soil types.

3.9. Sensory Qualities of Fresh and Stored A. digitata Jams

3.9.1. Sensory Qualities of Fresh Jam Products. The evaluation of the sensory qualities of the two fresh products in day 1 showed that the product of formulation no. 7 had higher acceptability ratings (82.4–95.3%) compared to the product of formulation no. 6 (78.7–93.3%). Jam products of formulation no. 7 received statistically higher mean ratings in four of the seven attributes, namely, aroma, flavor, overall

Table 8: Duration and temperature of storage on proximate composition of *A. digitata* jam products.

Storage conditions		Mean (±SD) proximate components (%)				
Time (days)	Temp. (°C)	Moisture	Ash	Crude fiber	Crude fat	Crude protein
(a) Formulation no. 6						
5	10–12	16.04 ± 0.05^{ab}	1.84 ± 0.15^{a}	3.25 ± 0.01^{a}	0.51 ± 0.01^{a}	0.41 ± 0.00^{a}
	25–27	16.10 ± 0.11^{a}	1.87 ± 0.18^{a}	3.25 ± 0.01^{a}	0.50 ± 0.02^{a}	0.41 ± 0.02^{ab}
30	10–12	15.95 ± 0.01^{b}	1.84 ± 0.22^{a}			
	25–27	15.92 ± 0.00^{b}	1.83 ± 0.26^{a}			
60	10–12	16.11 ± 0.01^{a}	1.82 ± 0.19^{a}			
	25–27	16.11 ± 0.01^{a}	1.36 ± 0.11^{b}			
90	10–12	16.15 ± 0.04^{a}	1.52 ± 0.04^{b}	3.22 ± 0.01^{b}	0.39 ± 0.00^{c}	0.39 ± 0.00^{c}
	25–27	16.12 ± 0.02^{a}	1.41 ± 0.04^{b}	2.97 ± 0.01^{d}	0.26 ± 0.01^{e}	0.26 ± 0.01^{e}
(b) Formulation no. 7						
5	10–12	14.97 ± 0.05^{dc}	1.83 ± 0.01^{a}	3.17 ± 0.01^{c}	0.49 ± 0.01^{a}	0.49 ± 0.01^{ab}
	25–27	15.08 ± 0.19^{c}	1.81 ± 0.02^{a}	3.16 ± 0.05^{c}	0.45 ± 0.06^{b}	0.45 ± 0.06^{b}
30	10–12	14.19 ± 0.18^{g}	1.83 ± 0.02^{a}			
	25–27	14.51 ± 0.01^{f}	1.85 ± 0.23^{a}			
60	10–12	14.57 ± 0.01^{f}	1.83 ± 0.06^{a}			
	25–27	14.48 ± 0.16^{f}	1.55 ± 0.14^{b}			
90	10–12	14.81 ± 0.02^{e}	1.55 ± 0.06^{b}	2.97 ± 0.01^{d}	0.32 ± 0.01^{d}	0.24 ± 0.00^{d}
	25–27	14.84 ± 0.02^{de}	1.46 ± 0.11^{b}	2.79 ± 0.01^{e}	0.24 ± 0.00^{e}	0.17 ± 0.01^{f}

Means (±SD) values in a row having different superscripts signify significant difference at $p \leq 0.05$.

Table 9: Mineral composition of the baobab fruit powder and jam products (mg/L).

SN	Mineral	Fruit powder	Formulation no. 6		Formulation no. 7	
			Amount	%*	Amount	%
1	Sodium	125.60 ± 0.10^{a}	42.40 ± 0.10^{c}	34	49.90 ± 0.34^{b}	40
2	Potassium	257.00 ± 0.00^{a}	127.60 ± 0.75^{c}	50	148.70 ± 0.25^{b}	58
3	Calcium	$2{,}514.10 \pm 0.97^{a}$	$1{,}063.30 \pm 1.15^{b}$	42	$1{,}063.30 \pm 5.50^{b}$	42
4	Magnesium	230.00 ± 0.11^{a}	186.70 ± 2.08^{b}	81	186.70 ± 1.52^{b}	81
5	Phosphorus	$1{,}524.00 \pm 0.1^{a}$	296.70 ± 0.60^{b}	19	300.60 ± 0.00^{b}	20
6	Iron	50.30 ± 0.07^{a}	22.90 ± 0.17^{b}	46	23.80 ± 0.14^{b}	47
7	Zink	2.40 ± 0.00^{a}	1.20 ± 0.00^{b}	50	1.10 ± 0.01^{b}	46
8	Copper	8.30 ± 0.00^{a}	3.60 ± 0.03^{b}	43	3.90 ± 0.05^{b}	47
9	Nitrogen	$10{,}450.40 \pm 0.24^{a}$	$2{,}130.00 \pm 0.01.29^{b}$	20	$2{,}133.30 \pm 1.44^{b}$	20

*: refers to the proportion of the minerals in fruit powder retained in the jams.

appearance, and overall liking ($p \leq 0.05$) (Table 10). Therefore, this study has showed that the formulations with higher sugar content were given higher ratings of sensory quality.

3.9.2. Sensory Qualities of Stored Jam Products. On day 45, the mean ratings of sensory quality attributes of both jam products stored at lower temperature (10–12°C) were slightly higher than products stored at higher temperature (25–27°C) (Table 10). But all the differences lacked statistical significance. On day 90, the differences in the mean ratings of the sensory quality of many attributes became statistically significant. Jam products of formulation no. 6 stored at lower temperature had significantly higher ratings in 6 of the 7 attributes than the products stored at higher temperature. Likewise, jam products of formulation no. 7 stored at lower temperature had significantly higher ratings in 5 of the 7 attributes ($p \leq 0.05$). These observations imply that *A. digitata* fruit jam products have to be consumed fresh or stored at lower temperature. The slight difference in the reduction of mean ratings in favor of the jams of formulation no. 7 might be attributed to the relatively higher sugar content that acts as a preservative by discouraging microbial activities and spoilage [40, 41].

3.10. Microbial Load of Fresh and Stored A. digitata Jams. Aerobic bacterial and fungal (yeasts/molds) growths were observed in samples tested on day 60 in both formulations and storage temperatures, while no coliforms were observed. The microbial growth, especially the growth of yeast and molds, was more prevalent in the jam products of formulation no. 6 stored at the higher storage temperature (Table 11). However, the detected numbers of microbes were lower than the acceptable limits (i.e., 1×10^6 CFU/g) for food products [42]. The findings of the present research were comparable to results of a similar study carried out in Tanzania [7]. It is plausible to assert that the low pH of the jam products is discouraging the growth of the microbes. The low level of microbial load can be ensured by taking proper measures towards creating a sterile and clean formulation environment.

Table 10: Effects of time and temperature of storage on sensory qualities of the jams.

Storage conditions		Mean (±SD) values of the sensory attributes						
Time (days)	Temp. (°C)	Color	Texture	Aroma	Flavor	Mouth feel	*Appearance	Overall liking
(a) Formulation no. 6								
1	Room temp	5.73 ± 0.06^{ab}	6.53 ± 0.21^{a}	5.50 ± 0.30^{b}	$5.53 \pm 0.25^{b-d}$	$5.53 \pm 0.31^{a-c}$	5.51 ± 0.24^{b}	5.90 ± 0.26^{bc}
45	10–12	5.77 ± 0.21^{ab}	6.50 ± 0.20^{a}	5.27 ± 0.12^{b}	5.33 ± 0.21^{dc}	5.37 ± 0.29^{bc}	5.47 ± 0.15^{b}	5.77 ± 0.15^{bc}
	25–27	5.33 ± 0.32^{bc}	6.13 ± 0.25^{a}	5.07 ± 0.15^{b}	5.07 ± 0.05^{d}	5.00 ± 0.26^{c}	5.07 ± 0.25^{bc}	5.40 ± 0.17^{c}
90	10–12	5.17 ± 0.15^{cd}	6.14 ± 0.13^{a}	5.08 ± 0.12^{b}	5.15 ± 0.09^{d}	5.17 ± 0.35^{c}	4.87 ± 0.31^{cd}	5.20 ± 0.36^{c}
	25–27	4.50 ± 0.26^{e}	5.53 ± 0.35^{b}	4.37 ± 0.15^{c}	4.30 ± 0.46^{e}	3.97 ± 0.78^{d}	4.43 ± 0.55^{d}	4.30 ± 0.89^{d}
(b) Formulation no. 7								
1	Room temp	5.77 ± 0.21^{ab}	6.50 ± 0.20^{a}	6.63 ± 0.15^{a}	6.40 ± 0.30^{a}	6.27 ± 0.21^{a}	6.67 ± 0.21^{a}	6.67 ± 0.21^{a}
45	10–12	5.80 ± 0.10^{a}	6.53 ± 0.38^{a}	6.37 ± 0.23^{a}	6.23 ± 0.15^{ab}	6.33 ± 0.15^{a}	6.63 ± 0.15^{a}	6.60 ± 0.26^{a}
	25–27	$5.57 \pm 0.23^{a-c}$	6.13 ± 0.31^{a}	6.11 ± 0.16^{a}	$6.03 \pm 0.32^{a-c}$	6.07 ± 0.15^{ab}	6.23 ± 0.15^{a}	6.23 ± 0.15^{ab}
90	10–12	5.27 ± 0.47^{c}	6.39 ± 0.29^{a}	6.17 ± 0.23^{a}	$5.83 \pm 0.35^{a-d}$	6.07 ± 0.46^{ab}	6.23 ± 0.15^{a}	6.37 ± 0.21^{ab}
	25–27	4.80 ± 0.10^{ed}	6.10 ± 0.20^{a}	5.30 ± 0.85^{b}	5.13 ± 0.96^{d}	5.03 ± 0.95^{c}	3.64 ± 0.60^{e}	5.30 ± 0.46^{c}

Means (±SD) values in a given row having different superscripts are significantly different at $p \leq 0.05$. * = overall appearance.

Table 11: Microbial analysis of jam.

Storage days	Jam formulation	Microbial count (CFU/g)					
		Storage temperature 1 (10–12°C)			Storage temperature 2 (25–27°C)		
		Aerobic bacteria	Yeast and molds	Coliforms	Aerobic bacteria	Yeast and molds	Coliforms
5	No. 6	—	—	—	—	—	—
	No. 7	—	—	—	—	—	—
30	No. 6	—	—	—	—	2	—
	No. 7	—	—	—	—	—	—
60	No. 6	2	1	—	2	3	—
	No. 7	—	1	—	1	1	—
90	No. 6	1	—	—	—	1	—
	No. 7	—	—	—	—	—	—

(—) = not detected.

4. Conclusion

This study has showed that baobab fruits of Tekeze Valley, Tigrai, Northern Ethiopia, are good sources of pulp powder with high amounts of carbohydrate, many macro and micronutrients, and fiber for preparing quality baobab jam products. It has also showed that sugar-to-powder ratios between 55 to 45 g and 60 to 40 g supplemented with 0.50 g ascorbic acid and 0.40 to 0.60 g citrus pectin jelling yielded excellent jam products with pH and TSS within acceptable ranges. Moreover, it has showed that storage of the products at higher temperature for three months reduced their nutritional qualities and sensory acceptability. Thus, it is advisable that household and small-scale jam products are consumed fresh or within weeks after their preparation. The data gained in this study can be used for refining the formulation protocol to make better products and devising better storage conditions and preservatives to retain nutritional qualities. Further research can also focus on devising mechanisms for maintaining the nutritional qualities and sensory acceptability of such products for so long.

Data Availability

The datasets used/analyzed in the current study are available from the first author upon reasonable request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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