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Research Article

A Comparative Analysis of the Physicochemical and Rheological Properties of Tamarind Fruit (*Tamarinds indicia* L) Nectar Produced through Conventional Heating and Microwave Pasteurization

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Abstract

Objective: Compare the effect of conventional thermal pasteurization and microwave pasteurization on the phenolic, carotenes, antioxidants, and vitamin C of tamarind.

Methods: Samples were brought from the local market in Wad-Madani, Sudan, washed, and soaked. Physiochemical analysis and rheological properties of tamarind nectar was determined with optimum formulated of tamarind nectar was established as follows: the flotation ratio (pulp: water) was 1:3 at pH 2.73.

Result: The total phenols and antioxidant activity of tamarind fruit were 25.12 ± 0.16 Mg/g and 68.40 ± 0.41 respectively. Tamarind nectar treated with conventional heating contained 60.57 mgL^{-1} vitamin C, 45 mg/100 ml total phenols, 520 mg/100 ml carotenoids and 76.3% antioxidant while tamarind nectar treated with microwave pasteurization contained 63.11 mgL^{-1} vitamin C, 60 mg/100 ml total phenols, 470 mg/100 ml carotenoids and 80.93% antioxidant.

Conclusion: One of the technological innovations that are frequently researched on a wide range of food products is microwave treatment, which causes rapid heat transfer and preserves the functional properties of foods. Microwaving had a positive effect on all samples and increases the total soluble solid, total sugar, and antioxidant in all tamarind fruit nectar. Therefore, microwave treatment could be used in place of thermal pasteurization.

Keywords: *Tamarind Fruit; Microwave; Thermal Pasteurization; Fruit Juices; Ascorbic Acid*

Introduction

The tamarind (*Tamarindus indica*, L.) tree is a tropical fruit grown in Africa and Asia that is highly valued for its pulp. Authentic Sudanese juices are consumed throughout the year and in Ramadan, in particular, by combining concentration methods with sugar and heat and then refrigerating without adding a preservative.

Fruit juices are among the most favored beverages, advantageous for individuals of all ages. They do not only satisfy human nutritional needs but also safeguard us against many ailments when ingested frequently from an early age. The quality of fruit juices must be preserved to prevent the risk of foodborne disease outbreaks. While fruit juices enhance our immune function, excessive consumption and contamination with foodborne pathogens can lead to harm. The quality assessment should commence with the selection of fruits for juicing, followed by harvesting, peeling, processing, incorporation of additives, packing materials, and storage conditions. Effective consumer management is crucial for mitigating the complexities associated with fruit juice use [1].

Juices are a vital component of a balanced diet and are strongly endorsed for their nutritional value and the presence of health-promoting substances. Juices are abundant in vitamin C, carotenoids, flavonoids, dietary fiber, and phytochemicals. Ascorbic acid and water-soluble polyphenols are the primary antioxidants found in several juices [2]. Fruit juice is a favored beverage due to its significant contribution of bioactive substances, including vitamins, phenolic compounds, anthocyanins, and carotenoids [3]. Tamarind (*Tamarindus indica* L.), a tropical fruit found in Africa and Asia, is highly valued for its pulp. The fruits contain fiber, sugars (namely, fructose, glucose, sucrose and maltose), acids, polysaccharides, small amounts of protein and lipid. Tamarind fruit pulp has a sweet acidic taste due to a combination of high contents of tartaric acid and reducing sugars. Tamarind fruit is most valued for its high ascorbic acid content, minerals and sugar [4].

Thermal pasteurization is a conventional physical method of food disinfection that remains widely utilized due to its efficiency, environmental sustainability, absence of preservatives, and cost-effectiveness relative to alternative preservation technologies. The application of mild temperatures to foods (> 95°C) for a designated duration facilitates enhanced preservation of the raw food's inherent characteristics while effectively inactivating vegetative pathogens, including Salmonella. The mild thermal treatment may result in the presence of potential microbial survivors, such as spore formers, in the food post-process. To ensure public safety, low-acid (pH < 4.6) raw and pasteurized foods are typically stored, transported, and sold under refrigerated conditions (temperature below 7°C) and have a limited shelf-life to reduce the proliferation of pathogenic microorganisms during distribution. When sterilization is implemented, all bacteria, including spore-forming varieties, will be rendered inactive, allowing for the safe storage of food at ambient temperature [5].

Microwave heating seems to be a promising innovative technology for food preservation. In recent decades, numerous studies have assessed the advantages of microwave treatment compared to traditional heating methods. Its efficacy in pasteurization, sterilization, and dehydration procedures, along with its potential to yield safe and superior quality goods, has been extensively validated [6].

This study set out to compare the effectiveness of conventional thermal pasteurization with that of newly available microwave technology in terms of selective qualitative aspects of traditional beverages.

Purpose of the Study

The purpose of this study was to analysis physicochemical and rheological properties of tamarind fruit (*Tamarinds indicia* L) nectar produced by conventional heating and microwave pasteurization.

Materials and Methods

This study was carried out at Food Technology Research Institute (FTRI), Ministry of Agriculture, Egypt.

Selection of fruits

Fresh tamarind fruits were acquired from the Wad-Madani market, Gezira state, Sudan. Only mature fruit should be utilized for nectar production; immature fruit, fruit that has passed its prime, or fruit that has rotting rapidly reflect such conditions in the nectar produced from it, decreasing the product's quality. Fruit washing and sorting were required during nectar fruit production process to ensure that dust and damaged fruits were entirely eliminated.

Processing of tamarind nectar

Tamarind nectar was prepared by mixing 100g pulp with 300 ml distill water. Every time, the mixture was stirred using magnetic stirrer for 20 minutes. For complete extraction the mixture was put in mixer 2000 rpm for one hour. The extracted nectar were filtrated through double layers of muslin cloth. Glass Bottles were washed thoroughly and sterilized by boiling them for 30 minutes then filled with concentrate tamarind nectar, tightly closed by metallic caps, pasteurized the nectar by thermal pasteurization and microwave and cooled immediately to room temperature. The product was reserved under freezing for further investigations, the total soluble solids (TSS) and pH was measured. Figure 1 shows unit operation for the formulation of tamarind functional nectar.

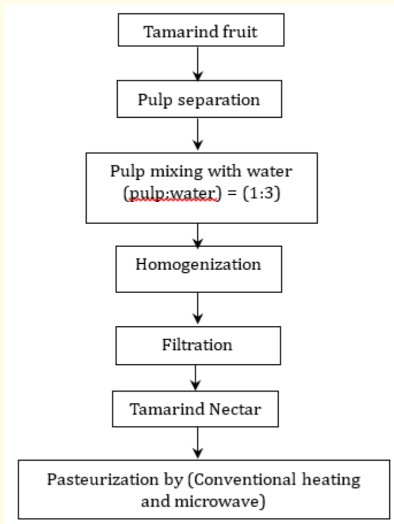


Figure 1: *Flowchart of unit operation for the formulation of tamarind nectar.*

Conventional thermal treatment

Thermal pasteurization was performed by heating the mixed nectar at 80°C for 10 minutes. The pasteurized nectar was filled in sterilized bottles and capped with sterilized caps. Then all the samples were cooled and stored at refrigerated temperature at 4°C for 3 months [7].

Microwave heating pasteurization

Processing of the natural tamarind nectar was carried out by heating in a microwave system with a conventional microwave oven (LGR MS-0745V, South Korea) at 100% power (490 W, 2450 MHz) [7].

Proximate analysis

Moisture (%) was determined in duplicate using a gravimetric method by [8], ash Content (%) was determined in duplicate by the gravimetric method according to [9]. Total Nitrogen was determined according to the Kjeldahl method as described by [9]. Total Dietary Fiber: (TDF) content was determined based on AACC according to [10]. Fat Content was determined by a Soxhlet extractor according to the standard NP ISO 6492, 2014 [11]. The total carbohydrate content was estimated by difference using the following formula:

Carbohydrates (%) = 100 - [moisture (%) + protein (%) + fat (%) + ash (%) + fiber (%)].

The medium value of 8.9 ± 0.05% was used for fat.

Extraction and quantification of vitamin C and organic acids

The primary organic acids, namely ascorbic acid (AA), citric acid (CA), malic acid (MA) and tartaric acid (TA), were extracted and measured via HPLC. Twenty milliliters of nectar was dissolved in forty milliliters of metaphosphoric acid at a concentration of 0.3 g/L, vortexed for twenty seconds at medium speed, then centrifuged at 4000 rpm for ten minutes at 4°C. The supernatant was filtered through Whatman No. 1 paper to get a clean filtrate. The solution was filtered with a Millipore 0.45 μm filter into amber glass vials. The concentration of Vitamin C was assessed following the conversion of dehydroascorbic acid to ascorbic acid utilizing 2-carboxy ethyl phosphine hydrochloride (TCEP, 5 mg/L). De hydroxyl ascorbic acid (DHA) was therefore quantified by difference due to its instability and the splitting of its peak in the C18 column during direct measurement. The quantification of organic acids was performed utilizing the ultra-fast liquid chromatograph (UFLC XR) apparatus detailed in the preceding section. A 20 μL sample volume was injected, and separations were performed on a Gemini C18 column (250 x 4.6 mm, 5 μm; Phenomenex, UK) maintained at 25°C. Separation was performed under isocratic conditions (0.5 mL/min; 15 minutes) utilizing 10 mM potassium dihydrogen phosphate (pH 2.6) as the mobile phase. Chromatograms of organic acids (citric acid, malic acid, and tartaric acid) and ascorbic acid were obtained at wavelengths of 210 nm and 254 nm, respectively. Quantification was accomplished via the external standard approach. A calibration was performed using a variety of organic acid standards with concentrations between 5 and 100 mg L^{-1}, exhibiting strong linearity ($R^2 > 0.999$), with results given in mg/100g FW. Spiked samples were incorporated to assess the method's sensitivity and repeatability, quantify % loss, and observe any alterations in the retention duration of certain organic acids. The degradation of vitamin C in tamarind nectar during storage was forecasted [12].

Physiochemical properties of nectar tamarind

Determination of pH

pH was determined in ten milliliters of the nectar dispensed into a beaker after calibration with phosphate buffer of pH 4.0 and 7.0 [13].

Determination of total titratable acidity (TTA)

For the measurement of the titratable acidity the standard method of [14] was used.

Determination of color

Color measurement was conducted utilizing a chromometer (Konica Minolta Chroma Meter CR-400, Japan) calibrated with a standard white tile. A volume of 25 mL of the sample was placed in a glass petri dish, covered with a protective cap, and the color measurement was recorded. The color characteristics were documented at ambient temperature, in accordance with CIE L*, a*, and b* color values. The L* value signifies lightness, the a* value denotes the spectrum from greenness to redness, and the b* value quantifies the range from blueness to yellowness of the sample [15].

Determination of viscosity

The viscosity of sample was determined using a rotatable viscometer (Brookfield DV-II+ Pro, USA) with no. 2 spindle at 100 rpm [15]. The position and setting of the viscometer were adjusted to obtain a precise measurement. Prior to the experiment, the spindle was immersed for 30s in the sample for equilibrium. The reading was taken when it became stable, basically after 10s of rotation or at 10th, 11th and 12th cycle. The measurement of viscosity was expressed in millipascal-second (mPas).

Total and reducing and non-sugars

Total and reducing sugars were determined according to Lane and Eynon titrimetric method. Non reducing sugars content was calculated as follows: None reduce sugars = Total sugars - reducing sugars.

Phytochemical properties determination

The prominent phytonutrients in tamarind nectar tested in this study were total vitamin C (ascorbic acid and dehydro-ascorbic acid), total polyphenol compounds and the antioxidant capacities and carotene.

Total phenolic content (TPC) and antioxidant activity (AA) determination

Tamarind nectar extracts for total phenolic content (TPC) and antioxidant activity (AA) were prepared in duplicate according to the protocol described by [16] with some modifications.

Determination of carotenoids

Carotenoids were determined according to [17].

Statistical analysis

For statistical analysis the obtained data were analyzed using simple descriptive statistics (e.g. mean and standard deviation) and ANOVA analysis at P-value (0.05).

Results and Discussion

Chemical composition of tamarind fruit pulp

The chemical composition of the tamarind fruit pulp was shown in table 1. The moisture content of the tamarind pulp was found to be 29.2%. This value falls within the range obtained by [18] who reported a value ranged between 17.8 - 35.8%, and was higher than the value 11.22% reported by [19]. The variation in moisture content of tamarind could be due to the storage conditions, environmental conditions, as known Sudan has a tropical climate which is hot most of the year. The ash represents total content of minerals in a food. In the present study, the ash content of tamarind fruit pulp was found to be 2.9%, this value falls within the range of the results obtained by [18] who reported a range of 2.6% - 3.9%. The variation in ash content could be attributed to the difference in environmental factors.

The protein content of tamarind fruit pulp was found to be 2.8%, which is slightly lower than that reported by [18] who reported a value of 3.1%, The differences in protein contents are probably associated with difference in environmental conditions in different areas. As shown in table 4, tamarind fruit pulp was found to contain low contents of crude oil which was 0.7%. These values was lower than those of [19] who recorded 4% and 1.99% values, respectively. The variation of these values could be attributed to the genetic variations. The value of crude fiber of tamarind was found to be 5.6% as shown in table 1 which was similar to the value 5.6% documented by [18] and greatly lower than the values 8.04% and 13.05%, reported by [19], respectively. As shown in table 1 the carbohydrates content of tamarind was found 58.5%, which was in close agreement to those reported by [18] and higher than that of [19] who reported a value of 55%. The greater amount of carbohydrate in tamarind fruit pulp can encourage its utilization in many fermented products such as vinegar production; it must be converted by enzymatic or acid hydrolysis to obtain a readily fermentable source of hexose sugar. Unavailable carbohydrates are considered as dietary fiber.

Content	Moisture	Ash	Fat	Protein	CHO	Fiber
Obtained	29.21 ± 0.3	2.89 ± 0.01	0.69 ± 0.03	2.79 ± 0.07	58.47 ± 0.3	5.62 ± 0.04

Table 1: *Chemical composition of tamarind pulp.*

***Results are expressed as mean ± standard deviation of three replicates.*

Total phenols and antioxidant activity of tamarind

Table 2 showed the total phenols and antioxidants activity content of tamarind. It could be observed that the total phenols and antioxidants activity (DPPH) content were 25.12 mg/g and 68.40%, respectively. These results are in slightly higher than the value of [20], who reported that *Tamarind indica* L. contained a large number of polyphenol compounds with potential for antioxidant activity. However, the quantities of antioxidants may vary with geographical location.

Tamarind pulp	Concentration
Total phenols (Mg/g)	25.12 ± 0.16
Antioxidant activity (DPPH)%	68.40 ± 0.41

Table 2: *Total phenols and antioxidant activity of tamarind fruit pulp.*

***Results are expressed as mean ± standard deviation of three replicates.*

Physiochemical properties of tamarind nectar

The physicochemical properties of tamarind were examined in table 3 which shows the effects of conventional and microwave heating pasteurization. Table 4 displays the samples' color measurements and their viscosity; all physicochemical analyses were conducted sugar-free.

Effect of conventional and microwave heating pasteurization on pH

The pH of tamarind nectar was observed 2.73 as stated in table 3. After pasteurization and microwave heating, the pH of the tamarind nectar samples was found to be 2.70 and 2.68. The impact of pasteurization and microwave heating on pH is seen in figure 2a. The hydrolysis of sucrose and the subsequent generation of lactic acid are two possible causes of the pH drop. Consistent with these findings, [21] also found that the pH of physalis juice decreased. The amount of sugars that dissolve in a beverage is called its total soluble solid (TSS). According to table 3, the TSS of the fresh tamarind nectar was 9.9 Brix before treatment, and it increased to 10.2 Brix after conventional pasteurization and 10.5 Brix after microwave pasteurization, respectively.

Effect of conventional and microwave heating pasteurization on TSS

One possible explanation for the rise in total soluble solids (TSS) is the addition of citric acid, but another is that the juice is concentrated to some degree by heat processing, which leads to water evaporation. This contradicts the findings of [22] who similarly found that combining orange and carrot juice reduced TSS. Conventional and microwave heating pasteurization effects on TSS are illustrated in figure 2b.

Effects of traditional and microwave heating pasteurization on titrable acidity

According to table 3 the titratable acidity of untreated tamarind beverage was 1.18%, whereas after conventional heating pasteurization it was 1.19 and after microwave heating pasteurization it was 1.20%. One possible explanation for the rise in titrable acidity is the oxidation of reducing carbohydrates. According to [22] these findings are consistent with that work. Results for titratable acidity after conventional and microwave heating pasteurization are displayed in figure 2d.

Analysis of ascorbic acid (Vitamin C) by conventional and microwave heating pasteurization

The ascorbic acid (Vitamin C) content of untreated tamarind nectar was 64.45 mgL^{-1} but following conventional heating pasteurization brought it down was 60.57 mgL^{-1}, and microwave heating pasteurization it increased to 63.11 mgL^{-1}, as indicated in table 3. The results of this study corroborated those of [22] who found that orange juice reduced in ascorbic acid (Vitamin C) when heated in a microwave. Ascorbic acid (Vitamin C) undergoes different reactions after conventional and microwave heating pasteurization, as shown in figure 2c.

Effect of conventional and microwave heating pasteurization on total phenolic contents

Table 3 shows that total phenolic concentrations changed by 45 mg/100 ml and 60 mg/10 ml after traditional and microwave pasteurization, respectively. The total phenolic content was found to be lower in the tamarind nectar that was heated conventionally as compared to the non-pasteurized nectar. In contrast, the total phenolic content of tamarind nectar treated with microwave pasteurization was 50 mg/100 ml, which is in line with the results shown by [7] for mango juice treated at 90°C for 60 seconds. Total phenolic content is impacted by both conventional and microwave heating pasteurization, as seen in figure 2f.

Analysis of the antioxidant activity of conventional and microwave heating pasteurization

Table 3 shows that the antioxidant activity of tamarind nectar decreased from 78.95 mg/L before pasteurization to 76.43 mg /L after conventional pasteurization and 80.93 mg /L after microwave heating, respectively. Both traditional and microwave heating pasteurization had an impact on antioxidant activity, as seen in figure 2h. The comparison between traditional and microwave pasteurization processing on the antioxidant activity of tamarind nectar. When broccoli florets were treated with non-ionizing radiation, similar results were observed by [22].

Total carotenoids concentration

The total carotenoids concentration in pasteurized tamarind nectar (520 mg/100 ml) was much lower than in fresh drink (530 mg/100 ml), and the drop was less in microwave-treated juice (470 mg/100 ml) compared to conventional pasteurization. In a study conducted by [22], it was shown that orange juice that had been thermally pasteurized at 90°C for 30 seconds had loss of total carotenoids ($P < 0.05$). The results of conventional and microwave heating pasteurization on total carotenoids are displayed in figure 2g.

Modifications to total sugar by conventional and microwave pasteurization

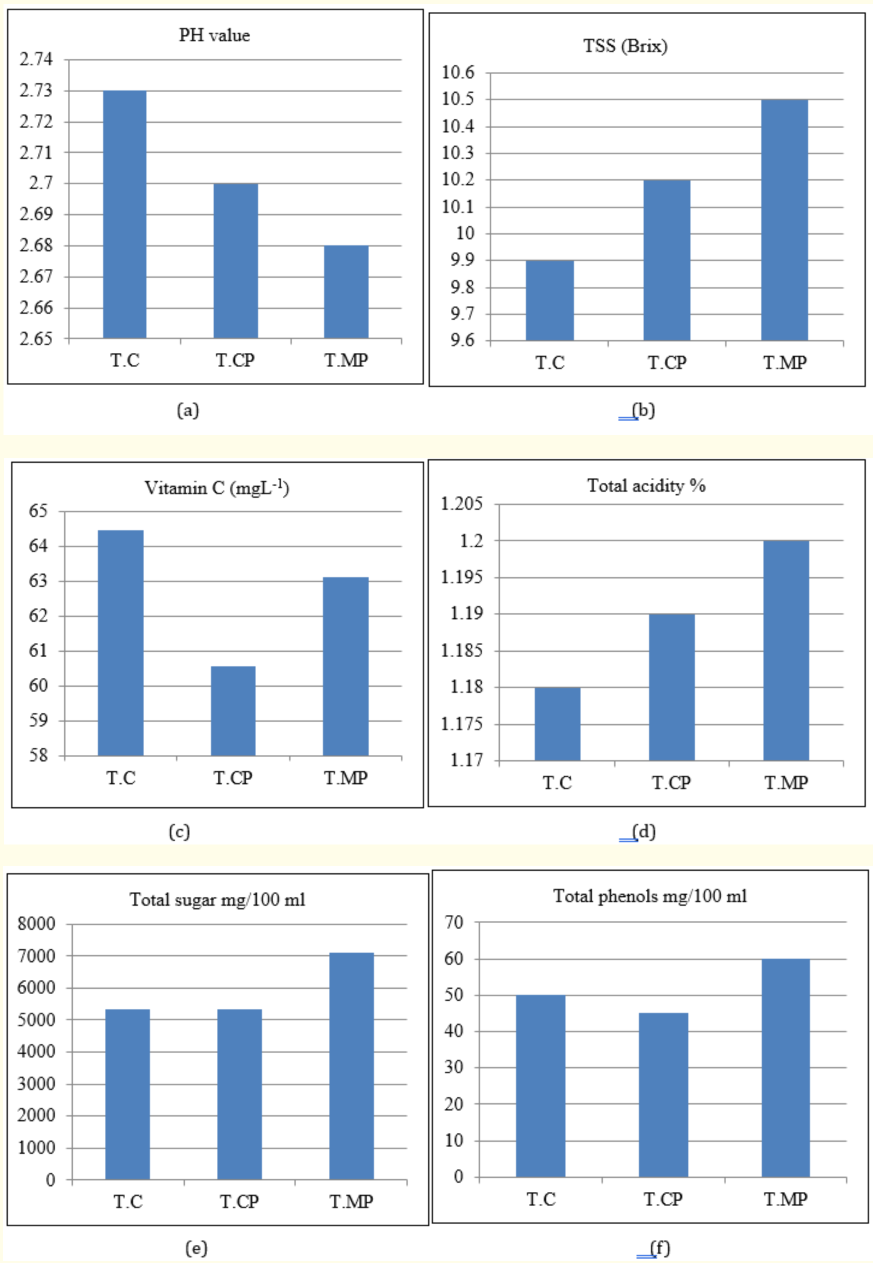
Table 3 shows that the total sugar content of fresh tamarind nectar was 5350 mg/100 ml before treatment, and after conventional heating pasteurization it was 5340 mg/10 0ml, and after microwave heating pasteurization it was 7120 mg/100 ml. A possible explanation for the rise in reducing sugar is the transformation of non-reducing sugars into reducing sugars. The impact of traditional and microwave heating pasteurization on total sugar is illustrated in figure 2e. The statistical analysis reveals a notable disparity in the parameters (rows level) with a p-value less than 0.05. This means that the physiochemical properties of tamarind nectar have been significantly affected by whether they are heated conventionally or using a microwave.

	Samples		
Parameters	**T.C**	**T.CP**	**T.MP**
PH value	2.73	2.70	2.68
TSS (Brix)	9.9	10.2	10.5
Vitamin C (mgL^{-1})	64.45	60.57	63.11
Total acidity %	1.18	1.19	1.20
Total sugar mg/100 ml	5350	5340	7120

Total phenols mg/100 ml	50	45	60
Carotenoids mg/100 ml	530	520	470
Antioxidant %	78.95	76.43	80.93

Table 3: *The effect of conventional and microwave heating pasteurization on physicochemical properties of tamarind nectar.*

T.C = Tamarind Control, T.CP = Tamarind Treated by Conventional Pasteurization, T.MP = Tamarind Treated by Microwave Pasteurization.



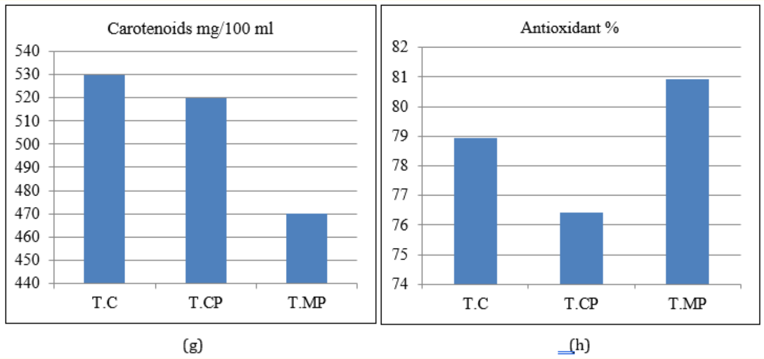


Figure 2: *The effect of conventional and microwave heating pasteurization on (a) pH (b) TSS (Brix) (c) Vitamin C mgL^{-1} (d) Total acidity % (e) Total sugar mg/100 ml (f) Total phenols mg/100 ml (g) Carotenoids mg/100 ml and (h) Antioxidant; of tamarind nectar.*

Effect of storage temperature on color value

The color index values of both fresh and thermally pasteurized samples are shown in table 4 which also demonstrates the effect of storage time. According to Hunter L, the visual color can be indicated by a* and b* or by a combination of the two. The initial L* value of fresh tamarind nectar was 27.24, which dropped to 26.23 following conventional pasteurization and 24.70 after microwave pasteurization. A significant drop ($P < 0.05$) is observed in the L values of both the untreated and thermally pasteurized nectar as the storage period progresses. The L* values of thermally pasteurized mixed orange and carrot juice dropped dramatically at 12°C, as reported by [22]. In [22], the authors also were noted that orange juice heated to 22°C loses some of its lightness. The positive a* value of tamarind beverage samples was enhanced from 4.03 to 0.39 and 1.05 after pasteurization by conventional and microwave respectively. On the contrary, positive b* value, slightly decreased from 10.16 for unpasteurized juice to 5.46 and 6.76 for conventional and microwave heating of tamarind nectar respectively by 30 days of storage.

Throughout the storage time, the chroma value of the fresh tamarind nectar was higher than that of the thermally pasteurized nectar, as shown in table 4. There was a significant decrease in chroma in all samples that were tested ($P < 0.05$). This suggests that the saturation of the nectar color decreases noticeably as its shelf life increases. The chroma of thermally pasteurized orange juice reduced when stored in the fridge at 2 - 10°C, according to a comparable finding by [22]. Researchers found that blood orange juice that had been thermally pasteurized had a decrease in chroma after being kept at 4°C for 7 weeks [22]. The samples' color degradation could be caused by nonenzymatic Maillard browning, a reaction involving organic acids, sugars, and amino acids. In addition, the color of juice may change due to heating, air and light, which cause carotenoids to undergo oxidation and alterations in epoxide rings as a function of storage [22]. The statistical analysis of table 4 show a significant difference in the rows level (parameters; P-value < 0.05), i.e. conventional heating of tamarind beverage or by using microwave has led to significant variations in their color value.

	Fresh tamarind				**conventional heating**				**Microwave heating**			
	Storage days											
Color value	**0**	**10**	**20**	**30**	**0**	**10**	**20**	**30**	**0**	**10**	**20**	**30**
L	27.24	26.99	26.11	25.77	26.23	25.01	23,99	23.54	24.70	23.12	21.86	20.69
a*	+4.03	+3.93	+3.54	+3.43	+0.39	+0.32	+0.27	+0.02	+1.05	+0.79	+0.53	+0.35
b*	+10.16	+8.01	+5.33	+5.39	+5.46	+4.43	+3.89	+2.72	+6.76	+6.55	+5.80	+4.77

Table 4*: Changes on color parameters (L*, A*, B*) of the fresh and pasteurized tamarind nectar during storage at 4°for 30 days.*

***Results are expressed as mean ± standard deviation of three replicates.*

The effect of different temperature on the viscosity

Rheological properties of tamarind nectar was measured using brookfield AMETEK at 5°C, 30°C and 50°C. As in appendices 1 and 2 the apparent viscosity decreased with increasing shear rate, while shear tress increased. All the samples exhibited non-Newtonian shear thinning behavior.

Conclusion

The study demonstrated that tamarind nectar can boost human health because it is full of phytochemicals and minerals. Tamarind fruit has far higher mineral content and antioxidant capacity. Microwave pasteurization of tamarind nectar increases the value of total soluble solid, total phenols; total sugar, Carotenoids and antioxidant while the vitamin C slightly decrease. Refrigeration at 4°C did not affect the pasteurized nectar. The prepared drink had potent antioxidant capabilities and high concentrations of ascorbic acid and total phenolic. The fact that it was well-received than commercial drinks further demonstrated its promise as a practical health beverage. The nectar has content high vitamin C aid in iron absorption, which may help avoid anemia. Tamarind nectar also has antioxidant qualities that, when taken in sufficient quantities, can make cells more resistant to oxidative stress. The importance of tamarind as an ingredient in functional drinks that promote consumer health is highlighted in this study. Even more importantly, it encourages the creation of novel baobab-based products by offering vital insights to the food industry. This not only improves the fruit's use but also opens up new avenues for growers and sellers to make money, which helps with sustainable development and income production.

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