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Effect of processing of tamarinds pulp into tamarind juice concentrate and appraisal of its quality characteristics

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Abstract

Tamarind (*Tamarindus indica, L*). fruits pulp (TFP) was processed into tamarind juice concentrate (TJC) using three different extraction methods: atmospheric pressure, flash evaporation, and batch pan evaporation, achieving concentrations of 12°, 24°, and 18° Brix, respectively. Sugar was added to reach 45–55° Brix for each method. The study evaluated the chemical composition, nutritional value, and calorie content of (TJC). Results indicated that (TJC) with 55% concentration contained significantly higher calories (265.59 Kcal for atmospheric pressure) compared to 45% concentration (194.89 Kcal for batch pan). The (TJC) was rich in sugar but low in fibre and protein. Differences in nutritional values were attributed to processing techniques and concentration levels. These findings highlight (TJC) potential as an energy-dense product with applications in food industries, particularly in developing countries where affordable caloric sources are essential.

Keywords: Tamarind, *Tamarindus indica*, tamarind juice concentrate, Sudan, soaking ratio, Concentration techniques, Nutritional composition, Energy content.

1. Introduction

Tamarind belongs to the dicotyledonous *Leguminosae* family, one of the largest plant families, comprising 727 genera and 19,327 species. The name "tamarind" originates from the Arabic term *Tamar-E Hind*, translating to "Indian date." This plant thrives in tropical and subtropical regions across the globe and has become naturalized in various locations, particularly in India, Southeast Asia, tropical areas of the Americas, Pacific Islands, and the Caribbean. Among the top producers are Asian countries such as India and Thailand (Reddy *et al*., 2024).

Tamarind holds significant value for its versatile uses, including direct consumption, culinary processing, and extraction for non-food purposes. It grows extensively in the subtropical and semiarid tropical regions and is cultivated across diverse areas in India. The species exhibits a high degree of cross-pollination, leading to substantial genetic variation (Malik *et al*., 2010). With rising global demand for tamarind pulp, alongside the decline in cultivable land and productivity, there is a pressing need to develop high-yielding tamarind genotypes. Identifying superior trees or genotypes is essential to ensure consistent productivity while safeguarding genetic diversity (Mayavel *et al*., 2024).

There are multiple varieties of (*Tamarindus indica* L.) generally classified into sweet and acidic types. Acidic varieties are more commonly found worldwide, thriving in warm, sunny climates, while sweet types are rarer (Reis *et al*., 2016). Tamarind Fruits offer two primary products: pulp and seeds. In Sudan, the pulp is either consumed directly, used in the preparation of traditional foods and beverages, or sold as a source of household income. After the pulp is removed, the seeds are usually discarded, although they are protein-rich (Okello, 2010; Taksene and Belay, 2024).

Fruit juices can be concentrated using various methods to retain their color, flavor, and nutrients, which makes them highly sought-after in the global market. Zia *et al*. (2024) explored several concentration techniques for apple, sour cherry, and peach juices. Demeczky *et al*. (1981) conducted a comparative evaluation of semi-concentrates made from sour cherry and peach juices, using reverse osmosis and vacuum thermal evaporation methods. Clarifying Fruit juices through physical or chemical processes reduces viscosity, making concentration more effective. Khamrus and Pal (2002) studied the concentration of Kinnow juice through reverse osmosis. However, specific details regarding the concentration of tamarind juice concentrate (TJC) from tamarind Fruit pulp (TFP) and the impact on quality remain unavailable.

Tamarind juice concentrate (TJC) is a practical product since it dissolves and reconstitutes easily in warm water. Because of its modest water activity, the product can also be kept for extended periods of time. The processing of (TFP) into (TJC) holds significant importance due to its versatile applications in food industries and its role as an affordable source of calories and nutrients, especially in developing countries. With the rising demand for tamarind-based products and limited studies on concentration techniques (Cardona-Herrera *et al.,* 2024), this research fills a critical gap by exploring efficient methods for producing (TJC) while preserving its nutritional quality. The study aims to evaluate different concentration techniques (atmospheric pressure, flash evaporation, and batch pan evaporation), assess their impact on the nutritional value and caloric content of the (TJC) final product, and identify optimal methods for industrial-scale production. This work contributes to enhancing the utilization of tamarind pulp in sustainable and scalable food processing systems.

2. Materials and methods

2.1. Preparation of Samples

Tamarind (*Tamarindus indica L.)* fruit samples were obtained from the local market in North Kordofan State (El-Obaid City), season 2014-2015, and then transported in sacks to the Food Laboratory, Department of Food Science and Technology, University of Khartoum, Shambat, Sudan. The tamarind samples were cleaned to remove foreign materials, the seeds were separated from the pulp.

2.2. Preservatives

Potassium meta-bisulphate ($K_2O_5S_2$), produced by Burgoyne and Burbidges Company, Mumbai, India (code No. 342), with a molecular weight of 222.33 and European number E224, was used as a preservative. A 0.125 g of Potassium meta-bisulphate was added per 1 L of juice.

2.3. Preparation of concentrated tamarind juices

2.3.1. Determination of soaking ratio

Different soaking ratios were tested to determine the most appropriate ratio for the production of juices. 100 grams of sorted, cleaned, and dehusked tamarind pods were soaked overnight in tap water at ratios of 1:2, 1:4, and 1:6. The extracted total soluble solids (TSS) were determined using a hand refractometer

2.3.2. Extraction of tamarind juices

The extraction process was carried out by trying three different techniques:

2.3.2.1. Concentration at atmospheric pressure

The process was carried out in The Food Research Centre (FRC), Shambat. Sorted, cleaned, and dehusked tamarind pods were soaked in tap water (ratio 1:4) in a laboratory vat overnight. The soaked material was then filtered through smooth fine textile and subsequently through a sieve.

2.3.2.1.1. Equipment Parameters and Experimental Circumstances

The open steam-jacketed kettle used for tamarind juice concentrate (TJC) production in this study is a Model OSK 1602, with a capacity of 60 litters. It features a heating surface area of 0.1964 m^2 and an evaporation rate of 0.143 K/min, which facilitates the concentration of tamarind juice from an initial 7° Brix to 12° Brix. This method employs steam pressure heating, ensuring uniform heat distribution across the kettle's surface for efficient evaporation.

To maintain optimal operation, the tamarind pulp was soaked overnight in a 1:4 water-to-pulp ratio, then filtered before being heated in the kettle. The concentration process was stopped at 12° Brix, followed by the addition of sugar to achieve a final concentration of 45–55° Brix, suitable for packaging and storage (Brooks et al., 2021).

2.3.2.2. Flash evaporation (vacuum type)

The processing was carried out in The University of Gezira, Faculty of Engineering and Technology, Department of Food Engineering and Technology. Unit operation laboratory. Sorted, cleaned, and dehusked tamarind pods were soaked to extraction in tap water (1:4 ratio) in laboratory vat for overnight. Then filtered through smooth fine textile prior to be filtered with sieve.

2.3.2.2.1. Equipment Parameters and Experimental Circumstances

The flash evaporator used in this study for tamarind juice concentrate (TJC) production is a Model MF-5T with a capacity of 10 liters, specifically designed for efficient concentration under vacuum conditions. Vacuum pressure was maintained at approximately 70 cm Hg, which significantly lowered the boiling point, helping to preserve the nutritional quality and sensory attributes of the tamarind juice.

The evaporator operates using hot water circulated in a double jacket to provide uniform heating, with the temperature controlled between 73–75°C. This low-temperature range is ideal for preventing thermal degradation of heat-sensitive compounds, such as sugars and organic acids. The heating surface area is optimized to enhance heat transfer, ensuring rapid and consistent evaporation.

The system has an evaporation rate of 0.054 K/min, allowing tamarind pulp initially at 7° Brix to be concentrated to 24° Brix. Afterward, sugar is added to achieve a final concentration of 45–55° Brix, suitable for TJC production (Paranjpe et al., 2012)

2.3.2.3. Batch pan evaporation (vacuum type)

The processing was carried out in the University of Khartoum, Faculty of Engineering. Department of Chemical Engineering. Unit operation laboratory.

Sorted, cleaned, and dehusked tamarind pod were soaked to extraction in tap water (1:4 ratio) in laboratory vat for overnight. Then filtered through smooth fine textile prior to be filtered with sieve.

2.3.2.3.1. Equipment Parameters and Experimental Circumstances

The batch pan evaporator used in this study is a Zuklwassej-Zulaufküler (Germany) model with a capacity of 4 liters, constructed from stainless steel for durability and corrosion resistance. The system operates under vacuum conditions of approximately 95 cm Hg, utilizing a steam-jacketed heating method to ensure uniform temperature distribution. The evaporator's heating surface is designed to enhance heat transfer efficiency, enabling controlled evaporation.

The evaporation temperature was maintained between 73–75°C to prevent thermal degradation of the juice's nutritional and sensory properties. The concentration process began with tamarind pulp at 7° Brix and was carried out until reaching 18° Brix, followed by the addition of sugar to achieve a final concentration of 45–55° Brix (Burke et al., 2014)

2.4. Determination of Tamarind Juices concentrate chemical component

Analysis of proximate composition was carried out on the dry base to determine the contents of crude protein, crude fat, crude fibre, moisture content, crude oil, ash and total carbohydrate according to (AOAC, 2006) methods. The total carbohydrate was obtained by calculation as the difference between the sum of the other major ingredients, moisture, ash, crude fibre, crude protein and fat from 100, i.e. Total carbohydrate content = 100-(% moisture + % crude protein + % crude fibre + % crude fat + % ash).

2.5. Nutritional value of Tamarind Juices concentrates

The average nutritional value of protein, carbohydrate, and fat were determined from the proximate analysis results and expressed as g/100 ml of concentrated juices.

For energy calculation the established and accepted data for energy conversion factors used in food labelling by McCance and Widdowson (2014) table was used.

In other instances, figures have been recalculated using the following criteria:

- Protein given as total nitrogen x 6.25
- Carbohydrates expressed as the weight of the carbohydrates themselves, not their monosaccharide equivalents
- Different factors are used to calculate energy values, as shown below

Table .1. Energy conversion factors used in food labelling

Component	Kcal	kJ
Carbohydrate expressed as weight	4	17
Protein	4	17
Fat	9	37
Alcohol	7	29
Organic acid	3	13
Sorbitol and other polyols	2.4	10

2.6. Statistical analyses

The collected data were statistically analysed using analysis of variance (ANOVA), using the general linear model procedure of Peterson (1985). Data for each test were analysed as a Completely Randomized Design (CRD). Differences among treatment means were separated using the Least Significant Differences (LSD) at $P \leq 0.05$

3. Results and discussion

3.1 Effect of soaking ratio on total soluble solids of crude tamarind juices concentrate (TJC)

Figure 2.1 shows the effect of soaking ratio on TSS% of juice extracted from tamarind fruits. There is a significant difference ($P \leq 0.05$) as TSS% decreases with increasing the water ratio, from 8.70° at 1:2 to 8.30° at 1:4, and 5.0° at 1:6. Adding more water beyond the 1:4 ratio did not significantly reduce the amount of soluble solids ($P \leq 0.05$).

Although the 1:2 ratio yielded the maximum TSS, the 1:4 ratio was selected as optimal due to its suitability for concentration techniques. This finding aligns with Mustafa (2007), who noted that a 1:4 tamarind-to-water ratio produces beverages with the best balance of flavour, colour, and acidity. Additionally, although the 1:3 ratio 1: 3 ratio required less sugar compared to the 1 : 4 ratio, it resulted in a highly acidic taste, which was not acceptable. The 1 : 5 and 1 : 6 ratios yielded low TSS, and the taste of tamarind extract was very weak. Abdelrahman (2011) reported that the tamarind –to- water ratio 1 : 4 was suitable for making dehydrated tamarind leather (tamaridin). Ahmed (2009) stated that the 1 : 3 ratio was best for manufacturing tamarind fruit powder.

The optimum soaking time for pulping tamarind recorded by Mustafa (2007) and Ahmed (2009) as 10 hours and 90 minutes respectively. However Abdelrahman (2011) found that three hours was the optimum soaking time. Overnight (12-10 hours) was used in this study to obtain maximum TSS.

Figure 2.1. Effect of soaking ratio on total soluble solids of (TJC).

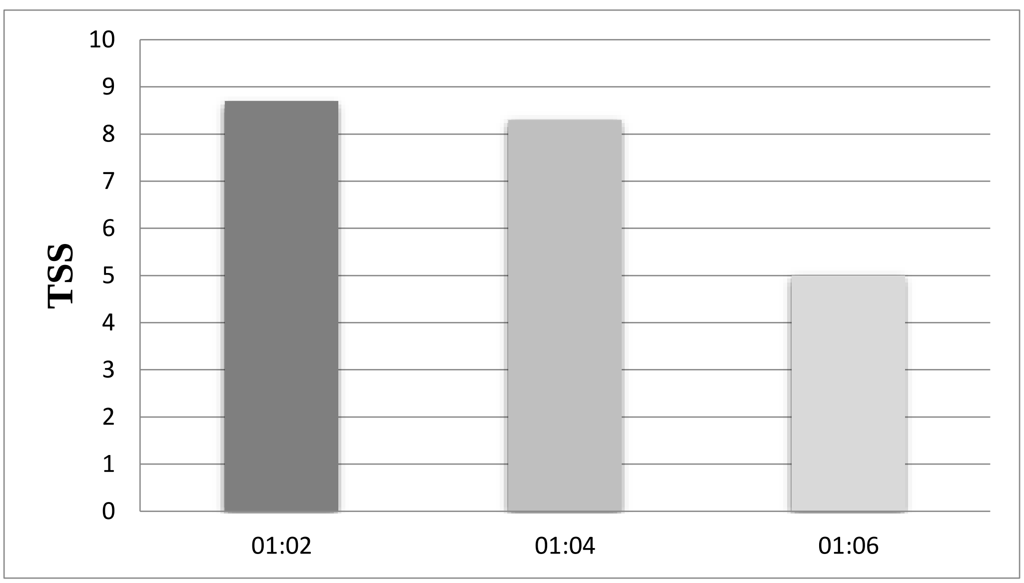

Table 2.1. Shows the effect of Concentration techniques and TSS on the chemical components of (TJC) on a dry base.

3.2. Effect of concentration techniques and TSS value on chemical component of tamarind juices concentrate

The moisture content of (TJC) was significantly different (P≤ 0.05), Clearly, the water content of (TJC) is much higher than that of tamarind fruits. This is due to the added water during the extraction and concentration of juice from the (TFP), the 45% concentration produced by different techniques had higher moisture content than those obtained with the 55% concentration. The moisture content at 55% concentration for open kettle, flash, batch pan evaporators was 57.00 %, 56.05 % and 59.33 % respectively. this is clearly due to the percentage of concentration of crude tamarind juices was the same, but the amount of water need to achieve 55% concentration was greater than that required for 45% concentration.

The oil content of (TJC) was significantly different (P≤ 0.05), the (TJC) produced by open pan under normal atmosphere had higher oil content (0.60 and 0.58 % for concentration 45 and 55%respectively) than (TJC) produced under vacuum, this may be due to the shorter exposure time to heat in open kettle evaporator than compared to that under vacuum. Atmospheric pressure required 45 - 60 minutes, while vacuum (flash and batch pan evaporators) required 120 -150 minutes. These findings agree with (Ashurst, 2005) who stated that the lipids rarely exceed 1% of the weight of most fruits and lower in fruits juices. Fruits in general are not considered to be significant sources of fat and the process of extracting fruit juice effectively removes most fat from the final product.

The fiber content of (TJC) were showed significantly different (P≤ 0.05), the (TJC) produced by batch pan evaporator had higher fiber content (0.26 and 0.61 % for concentration 45 and 55%respectively) than those produced by other evaporators. This may be due to the low temperature of batch pan evaporator (70- 75ºC) which was insufficient to destroyed fibrous substances during concentration of crude tamarind.

The ash content of (TJC) were also showed significantly different (P≤ 0.05), the (TJC) produced by batch pan evaporator 45 % concentration had the highest ash content (0.61 %). While the lowest ash content (0.18 %) was observed in (TJC) produced by flash evaporator at 45% concentration. this may be due variations in the preparation and filtration of crude tamarind pulp prior to processing and concentration of crude tamarind.

There was no significant different (P≤ 0.05) in the crude protein of (TJC) produced by different techniques of evaporation and concentrations. However, the (TJC) produced by the open pan 45% concentration had the highest protein content (0.53 %), while the lowest value (0.38%) was observed in (TJC) produced by batch pan evaporator at 55% concentration.

The carbohydrate content of (TJC) showed significantly different (P≤ 0.05). The (TJC) produced by the open pan under normal atmosphere at 55% concentration had the highest carbohydrate content (50.49%). In contrast, the (TJC) produced by batch pan evaporator at 45% concentration had the lowest value (39.21%). This may be due to different in the amount of sugar added to reach 45 and 55%. Concentration.

Table 2.1. compares the chemical composition (moisture, oil, fiber, ash, protein, and carbohydrate content) of tamarind juice concentrate (TJC) produced using different concentration techniques (atmospheric pressure, flash evaporator, and batch pan evaporator) and TSS levels (45% and 55%). It highlights significant variations in components based on the technique and TSS concentration.

2.3. Effect of concentration techniques and TSS value on tamarind juices concentrate nutritional value:-

Table 2.2. Shows the composition of (TJC) produced by different types of concentration techniques and different evaporators used in this study as the main ingredients (oil content, protein content, carbohydrate content, titratable acidity) and its specific gravity.

Table 2.3. Shows the calculation of nutritional components (g/100 ml) based on the apparent density (g/ml) of (TJC). For energy calculation, the energy conversion factors used in food labelling were those provided by McCance and Widdowson (2014)

Table 2.4. Shows the energy content per 100 ml of (TJC) (as Kcal) for the mains ingredient (oil content, protein content, carbohydrate content, organic acids) and the total energy as kilocalories (Kcal) and kilojoules (kJ). There is significant difference (P≤ 0.05) among the (TJC) produced by different mean of concentration techniques and TSS levels in their nutritional value (Kcal and kJ). The (TJC) at 55% concentration had significantly (P≤ 0.05) higher calories than 45% concentration. (TJC) produced by open pan at 55% concentration had the highest value (265.59

Kcal, 1111.23 kJ). In contrast (TJC) produced by batch pan evaporator 45% concentration had the lowest value (194.89 Kcal, 815.42 kJ). Carbohydrate were the major energy supplier, which can be attributed to the sugars added to reach 45 and 55% concentration. These results agree with Palmer (1998), who reported fruit juices provide dietary water, carbohydrate, vitamins, mineral, and some protein.

Table 2.1 Effect of Concentration techniques and TSS on chemical component of tamarind concentrate juices (TJC)

Concentration techniques	TSS %	Moisture Content (%)	Oil Content (%)	Fiber Content (%)	Ash Content (%)	Protein Content (%)	Carbohydrate Content (%)
atmospheric pressure (Open pan) 12% Tamarinds	45	57.00[a] (±1.814)	0.60[a] (±0.092)	0.0[b] (±0.00)	0.45[b] (±0.009)	0.53[a] (±0.204)	41.42[e] (±2.034)
	55	48.11[b] (±3.534)	0.58[a] (±0.005)	0.0[b] (±0.000)	0.41[b] (±0.006)	0.40[a] (±0.130)	50.49[a] (±4.982)
Under vacuum (flash evaporator) 24% Tamarinds	45	56.05[a] (±2.375)	0.3[b] (±0.020)	0.0[b] (±0.000)	0.18[c] (±0.030)	0.43[a] (±0.034)	43.05[d] (±5.043)
	55	53.31[b] (±1.508)	0.14[b] (±0.003)	0.09[b] (±0.001)	0.60[a] (±0.002)	0.43[a] (±0.230)	45.43[c] (±3.975)
Under vacuum (batch pan evaporator) 18% Tamarinds	45	59.33[a] (±1.058)	0.12[b] (±0.061)	0.26[b] (±0.030)	0.61[a] (±0.007)	0.47[a] (±0.140)	39.21[f] (±3.907)
	55	51.43[b] (±2.045)	0.16[b] (±0.047)	0.61[a] (±0.050)	0.55[a] (±0.073)	0.38[a] (±0.239)	46.84[b] (±5.003)

*Means in the same column with different letters are significantly different ($P \leq 0.05$) according to least significant test (LSD)
*Each value in the Table is a mean of three replicates ±S.D

Fruits juices are important for delivering body fluid and essential micro-nutrients such as vitamins (Landon, 2007). The nutritional significance of food nutrients is related to their contribution to the recommended dietary allowance (RDA) (Wardlaw, 2004).

The results of this study align with prior research on fruit juice concentration methods, including those applied to tamarind. For instance, Ashurst (2005) highlighted that fruit juices typically contain less than 1% fat, with most fat being removed during the extraction process. This observation is consistent with the findings of this research, where tamarind juice concentrate (TJC) exhibited low lipid levels across various concentration techniques. Similarly, the high carbohydrate content in (TJC) supports Palmer's (1998) assertion that fruit juices are a significant source of dietary carbohydrates, contributing substantially to their energy value. This study confirms that carbohydrates account for the majority of the energy in (TJC), especially in samples concentrated to 55° Brix, making it an energy-dense product.

The titratable acidity of (TJC) varied depending on the concentration method, consistent with findings by Kumar et al. (2023) on citrus juices. Kumar's study showed that the acidity of kinnow juice decreases with longer treatment times but increases with higher treatment temperatures. Likewise, this study observed that (TJC)'s acidity levels were influenced by the processing technique, with open-pan evaporation resulting in reduced acidity due to extended heat exposure.

Zia et al. (2024) reported that high-temperature evaporation methods for sour cherry and peach juices caused reductions in volatile compounds and antioxidants while achieving the desired concentration levels. This aligns with our findings, where sensory attributes and minor losses in protein and fiber were observed in (TJC) produced via open-pan methods, though it retained a carbohydrate-dense profile.

Khamrui and Pal (2002) further validated these results in their work on Kinnow mandarin juice, where open-pan evaporation at higher temperatures led to significant sugar concentration but reduced titratable acidity. Similarly, (TJC) produced at atmospheric pressure in this study exhibited high carbohydrate levels but lower acidity, a consequence of prolonged exposure to heat.

In contrast, Paranjpe et al. (2012) demonstrated the advantages of low-temperature techniques, such as flash vacuum expansion, in preserving antioxidants and maintaining sensory properties. This study confirmed similar benefits, with (TJC) processed through flash evaporation showing higher acidity retention and better protein preservation compared to open-pan methods.

Moreover, Demeczky et al. (1981) found that vacuum thermal evaporation enhanced flavor and nutritional quality in semi-concentrates of sour cherry and peach juices. In parallel, this research observed that batch pan and flash evaporation methods were effective in preserving moisture and fiber content in (TJC), further supporting the efficacy of low-temperature techniques in maintaining product quality.

Table 2.2. Nutritional composition of (TJC) and Specific gravity

Concentration techniques	TSS %	Oil Content g/100 ml	Protein Content g/100 ml	Carbohydrate Content g/100 ml	Titratable acidity %	Specific gravity (g/cm3)
atmospheric pressure (Open pan) 12% Tamarinds	45	0.60[a] (±0.092)	0.53[a] (±0.204)	41.42[e] (±2.034)	1.46[c] (± 0.099)	1.2216[b] (±0.004)
	55	0.58[a] (±0.005)	0.40[a] (±0.130)	50.49[a] (±4.982)	1.37[c] (± 0.099)	1.2721[a] (±0.009)
Under vacuum (flash evaporator) 24% Tamarinds	45	0.3[b] (±0.020)	0.43[a] (±0.034)	43.05[d] (±5.043)	2.70[b] (± 0.010)	1.2124[d] (±0.001)
	55	0.14[b] (±0.003)	0.43[a] (±0.230)	45.43[c] (±3.975)	3.00[a] (±0.010)	1.2415[a] (±0.007)
Under vacuum (batch pan evaporator) 18% Tamarinds	45	0.12[b] (±0.061)	0.47[a] (±0.140)	39.21[f] (±3.907)	3.00[a] (±0.283)	1.2191[b] (±0.001)
	55	0.16[b] (±0.047)	0.38[a] (±0.239)	46.84[b] (±5.003)	2.55[b] (±0.064)	1.2680[a] (±0.001)

*Means in the same column with different letters are significantly different (P≤ 0.05) according to least significant test (LSD)

*Each value in the Table is a mean of three replicates ±S.D

This table presents the nutritional composition (oil, protein, carbohydrate content, and titratable acidity) and specific gravity of tamarind juice concentrate (TJC) produced under different concentration techniques and TSS levels. The data provide insights into the nutritional profile of the concentrate.

This table calculates the nutritional components (oil, protein, carbohydrate, and organic acids) of tamarind juice concentrate (TJC) based on its apparent density. It compares the values across different concentration techniques and TSS levels.

4. Conclusion

(TFP) can be effectively used for producing (TJC) as a cost-efficient source of sugar and calories, particularly in developing countries. While the flash evaporator was the most efficient, the open pan evaporator is more accessible and practical for local production in regions with limited resources.

Table 2.3. Calculation of nutritional component of (TJC) as relevant to apparent density (g/ml)

Concentration techniques	TSS %	Oil Content g/100 ml	Protein Content g/100ml	Carbohydrate Content g/100 ml	Organic acids w/v
atmospheric pressure (Open pan) 12% Tamarinds	45	0.73[a] (±0.092)	0.65[a] (±0.204)	50.60[e] (±2.034)	0.146[c] (±0.004)
	55	0.74[a] (±0.005)	0.51[a] (±0.130)	64.23[a] (±4.982)	0.137[c] (±0.009)
Under vacuum (flash evaporator) 24% Tamarinds	45	0.36[b] (±0.020)	0.52[a] (±0.034)	52.19[d] (±5.043)	0.270[b] (±0.001)
	55	0.17[b] (±0.003)	0.53[a] (±0.230)	56.40[c] (±3.975)	0.300[a] (±0.007)
Under vacuum (batch pan evaporator) 18% Tamarinds	45	0.15[b] (±0.061)	0.57[a] (±0.140)	47.80[f] (±3.907)	0.300[a] (±0.001)
	55	0.20[b] (±0.047)	0.48[a] (±0.239)	59.39[b] (±5.003)	0.255[b] (±0.001)

Table 2.3 summarizes the energy content per 100 ml of tamarind juice concentrate (TJC), including the contributions of oil, protein, carbohydrate, and organic acids. The results are presented in both kilocalories (Kcal) and kilojoules (kJ) and are categorized by concentration techniques and TSS levels

Table 2.4 Energy content per 100 ml of (TJC) as Kcal

Concentration techniques	TSS %	Oil Content Kcal	Protein Content Kcal	Carbohydrate Content Kcal	Organic acids Kcal	Energy content as Kcal	Energy content as kJ
atmospheric pressure (Open pan) 12% Tamarinds	45	6.60[a] (±0.092)	2.59[a] (±0.204)	202.39[e] (±2.034)	0.0146[c] (±0.004)	211.59[b] (±2.000)	885.29[b] (±2.000)
	55	6.64[a] (±0.005)	2.03[a] (±0.130)	256.91[a] (±4.982)	0.0137[c] (±0.009)	265.59[a] (±2.832)	1111.23[a] (±2.832)
Under vacuum (flash evaporator) 24% Tamarinds	45	3.27[b] (±0.020)	2.09[a] (±0.034)	208.78[d] (±5.043)	0.027[b] (±0.001)	214.17[b] (±1.000)	896.09[b] (±1.000)
	55	1.57[b] (±0.003)	2.14[a] (±0.230)	225.66[c] (±3.975)	0.030[a] (±0.007)	229.40[a] (±2.000)	959.81[a] (±2.000)
Under vacuum (batch pan evaporator) 18% Tamarinds	45	1.37[b] (±0.061)	2.29[a] (±0.140)	191.20[f] (±3.907)	0.030[a] (±0.001)	194.89[b] (±0.803)	815.42[b] (±0.803)
	55	1.83[b] (±0.047)	1.93[a] (±0.239)	237.57[b] (±5.003)	0.0255[b] (±0.001)	241.36[a] (±0.309)	1009.85[a] (±0.309)

*Means in the same column with different letters are significantly different (P≤ 0.05) according to least significant test (LSD)

*Each value in the Table is a mean of three replicates ±S.D

5. study Limitations and future implication

5.1. Limitations of the Study

1. Limited Geographic Scope: The study relied on tamarind samples from a single region, which may not represent broader variability.
2. Seasonal Variation: Only one harvest season was examined, limiting insights into seasonal impacts on quality.
3. Laboratory Scale: The methods tested were not scaled for industrial production.
4. **Nutritional Analysis: Focus was on macronutrients, leaving micronutrients like vitamins unexplored.**

5.2. Future Implications:

1- Industrial Applications: (TJC) has potential as a high-energy product (up to 265.59 Kcal per 100 ml) potent energy source, particularly in developing countries.

2- Market Expansion: Findings pave the way for introducing tamarind-based products to global markets, especially in health-conscious sectors.

3- Nutritional Optimization: Enhancing (TJC)'s fiber and protein content could improve its nutritional balance.

5.3. Future Perspectives

The findings encourage further exploration into micronutrient retention during processing and scaling these concentration techniques for broader industrial applications, focusing on sustainability and energy efficiency.

Conflict of Interest

The authors have declared that no conflict of interest exists.

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