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Research Article

Physico-Chemical Properties of Tamarind *(Tamarindus indica L.)* Leather Affected by Different Drying Methods and Thickening Agents

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Abstract

Tamarind (*Tamarindus indica* L.) is a tropical fruit that belongs to the Leguminosae family. The value-added products of tamarind are leather, concentrated juice, paste, sauce, jelly and candy. Fruit leather is dehydrated fruit-based confectionary dietary product which is often eaten as a snack. The experiment was carried out at the laboratory of Food Science and Technology Department, Yezin Agricultural University, Nay Pyi Taw from September 2024 to August 2025. The experimental design was 2 × 5 factorial arrangement in a randomized complete block design (RCBD) with four replications. The first factor was drying methods of hot air oven drying (at 70°C) and open sun drying while the second one was different thickening agents of cassava starch, corn starch and carboxymethyl cellulose (CMC), respectively. The leather containing neither thickeners nor sugar was treated as control and 60% of sugar was added to every treatment except control. Drying time and water activity (aw) were recorded at every two hours while total soluble solid (°Brix), total titratable acidity (TTA), pH, color (a*) value and moisture content were weekly collected during the storage. However, the data on crude fiber and ascorbic acid were monthly recorded as well as microbial analyses (cfu/g) were recorded at 0 day and 3 months.

There were highly significant differences in moisture content, TSS, TTA, pH, ascorbic acid and crude fiber contents of tamarind leather. In comparison of drying methods, the hot air oven methods took 8-10 hours to reach water activity of 0.62. However, sun drying took 10-20 hours to achieve the same value. There was a decreasing trend in TSS, pH, ascorbic acid, and fiber, while TTA and moisture content gradually increased throughout the storage period. The combination of sun drying combined and CMC resulted in the highest microbial load whereas hot air oven drying with cassava starch in leather making showed the lowest microbial load. This study revealed that cassava starch is the best thickening agent and the hot air oven method is the most efficient drying method among the treatments.

Keywords: Tamarind Leather; Drying Methods; Thickening Agents; Microbial Load

Introduction

Tamarind (*Tamarindus indica* L.) is a tropical fruit that belongs to the family Leguminosae. It is native to Africa but also it grows in India, Pakistan, and many other tropical regions. 'Tamarind means 'date of India and the fruit is a good source of calcium, phosphorus, iron and vitamins and also contains small amounts of vitamins A and C [1]. In the world, the main production countries of tamarind are India, Thailand, Indonesia, Mexico and Nigeria. India is the largest producer and exporter of tamarind pulp with 45% of tamarind trees are planted only for fruit pulp with the production around 300,000 tons annually for food and medicinal value [2].

In Myanmar, 18,615.5 hectares of tamarind were cultivated and 153,022.77 tons of tamarind were produced [3]. The fruit is mainly produced in Mandalay, Sagaing and Magway regions in the central dry zones and the harvesting season is only once a year in summer especially in April [4].

Tamarind fruit can be processed into concentrated tamarind juice, paste, sauce, candy and jelly. Tamarind paste has many culinary uses including a flavoring for chutneys, curries and the traditional drink. Tamarind sweet chutney is popular in India as a dressing for many snacks. Fruit leather is also called a fruit bar or a fruit slab and it is a dehydrated fruit-based confectionary dietary product that is often eaten as a snack or dessert. The physicochemical properties of tamarind leather were 16.96 percent moisture content, 4.36 percent protein, 1.05 percent crude fat, 73.05 percent carbohydrate, 4.14 percent ash content, 1.92 percent acidity (tartaric acid), and a pH value of 3.91, as reported by [5].

Drying is important for removing moisture from a product [6] and it is one of the oldest methods of food preservation to extend the shelf life with year-round availability. On the other hand, drying methods significantly effects on the quality characteristics of dried fruits including texture, color, nutrient retention, flavor, and shelf life. Different drying techniques of sun drying, hot air drying and solar drying have distinct impacts due to variations in temperature, exposure to oxygen and drying time. The dried products not only extend the storage life but also reduce the volume and transportation cost by reducing postharvest losses [7]. Hot air drying is an alternative drying method and it can decrease drying time and improve the quality of dried product [9]. The sun-dried leather resulted in poor quality due to higher moisture content and degradation of vitamin C with titratable acidity and a drastic color change, which caused browning [7]. Open sun drying is a common way to preserve food and is an inexpensive way and cost effective to dry it out. However, the product may be spoiled due to dust, dirt, fungi, bacteria, and animal [9].

Tamarind leather is a traditional snack and it is extracting the pulp, mixing it with sugar or other sweeteners by drying into a firm, leathery sheet or roll. The final equilibrium moisture content of 15-25% with the water activity of 0.65. Once well-dried, the leather is packed in semi-transparent aluminum foil packs and stored at room temperature for 9 months [10,11]. A thickening agent also plays a crucial role in achieving the desired texture, consistency, and shelf stability in leather making. Thickening agents can increase the viscosity by binding water and fruit pulp preventing separation to get the desired texture by creating a smooth, uniform consistency when dried. It can extend the shelf life by lowering water activity that prevented microbial growth and quality development of leather [12]. The common use thickening agents are cassava starch, cornstarch, carboxymethylcellulose (CMC), pectin, agar, gelatin, and guar gum. In adding sugar, it is also used as a preservative, flavor, color, and bulking agent, and it inhibits microbial growth and spoilage, so it extends the shelf life of leather [13].

Cassava starch is a gluten-free ingredient extracted from the cassava root, used for thickening and binding in various applications [14]. Cornstarch is an important thickener in the production of many food products and that has been widely used as a stabilizer [15]. Carboxymethylcellulose provides significant viscosity, excellent suspension ability, and clarity by creating a distinct gummy texture at excessive levels [16].

Tamarind is a plentiful indigenous fruit in Myanmar and value-added products from tamarind should be developed. The products of tamarind are increasingly profitable for farmers and small-scale processors. In Myanmar, there is limited academic information and literature on tamarind leather influenced by different drying methods and thickening agents. Therefore, this study was conducted to determine the physico-chemical properties of tamarind leather influenced by different drying methods and thickening agents and to investigate the suitable drying methods and/or thickening agents for making tamarind leather.

Materials and Methods

Experimental site and Duration

The experiment was conducted at the laboratory of Food Science and Technology Department, Yezin Agricultural University, Nay Pyi Taw from June 2024 to September 2025. The experiment was carried out in a randomized complete block design (RCBD) with a 2 × 5 factorial arrangement for four replications. The first factor was types of drying methods (hot air oven drying and open sun drying) while the second one was different thickening agents including cassava starch, cornstarch, and carboxymethyl cellulose (CMC). The leather containing neither thickeners nor sugar was treated as control and 60% of sugar was added to every treatment except control.

Procurement of tamarind leather

Raw tamarind was collected from the local market and they were soaked in lukewarm water (1:2) for 1 hour. The tamarind puree was filtered by sieving to separate the fiber and seed. The procedure for tamarind leather making was carried out in several stages of ingredients, mixing of ingredients, cooking and drying. Firstly, the 5% (w/w) [17] of cassava starch, corn starch, and carboxymethyl cellulose were weighed and added according to treatments. And then, 60% of sugar was added according to the treatments except control and 1% salt was added to every treatment. The mixture was cooked at low heat until it reached a temperature of 70-90°C for 30 minutes, then stirred until the volume was half. The heated purees were spread on stainless steel trays and they were dried by hot air oven drying (at 70°C) and open sun drying (at 25-38°C) with 50-55% RH. The drying processes were done to reach the water activity of 0.62 and the final dried leather was packed in an aluminum foil pack and then stored at room temperature up to 3 months.

Data collection

The data on drying hours and water activity were collected at every 2 hours and total soluble solid (°Brix), total titratable acidity (TTA%), pH and redness (a*) were weekly collected. However, moisture content, ascorbic acid (mg/100), and crude fiber content were monthly recorded as well as microbial analysis (cfu/g) was also analyzed at day 0 and 3 months. The total soluble solid (°Brix) of the tamarind leather sample was measured using a pocket digital refractometer (RUDOLPHJ47 automatic, Tokyo, Japan) and water activity (a_w) was measured by using a pocket water activity meter (WA-60A). The total titratable acidity (TTA%) of tamarind leather was determined by the acid-base titration method [18] and pH was measured using a laboratory pH meter (PHOENIX Instrument, EC-45). The color was measured by using a handheld digital Minolta (NR-20XE) to determine the color coordinate redness (a*) and the ascorbic acid content (mg/100 g) was determined by the titration method [19] as well as moisture content was measured by the hot air oven drying method [20]. Crude fiber content of tamarind leather was measured by using the Velp Scientific ANKOM 200 fiber analyzer [18]. The microbial population (cfu/g) was measured by the serial dilution method [21].

Statistical analysis

All collected data were statistically subjected to analysis of variance (ANOVA) using Statistix 8.0 version software, and treatment means were compared using the least significant difference (LSD) test at a 5% level of significance (P ≤ 0.05).

Results and Discussion

Drying time of tamarind leather

Effect of different drying methods and thickening agents on drying time (hours) of tamarind leather is presented in Figure 1. Different drying methods have varying drying times and properties to achieve the final equilibrium moisture content. In the hot air oven drying, the control (100% tamarind) was dried for 10 hours to reach 0.62 water activity. The combination of tamarind puree and sugar dried with the hot air oven method took 8 hours, however, adding thickening agents that treatments took 6 hours to achieve the same value of 0.62.

In the sun drying, the control (100% tamarind) took 20 hours for drying time and the amount of water gradually decreased. The combination of tamarind puree, sugar and thickening agents dried with this method took 10 hours to reach 0.62 water activity. In contrast, the hot air oven drying method, which achieved the shortest drying time compared to sun drying method. This might be due to the hot air oven maintained constant high temperature inside the oven and that may encourage high water loss and a shorter drying period. The leather treated by thickening agents were minimized the drying time than without thickening agents. This may be due to the addition of thickening agent treated on tamarind. The addition of hydrocolloids (pectin and starch) reduced the drying time by half and also reduced the initial moisture content of fruit pulps containing hydrocolloids [22].

Moisture content of tamarind leather

Effect of different drying methods and thickening agents on moisture content (%) of tamarind leather is presented in (Table 1). There was highly significant difference on moisture content in all treatments by different drying methods and thickening agents. Moisture content was slightly increased during the storage days. It is similar with the finding of [23], the moisture content of peach

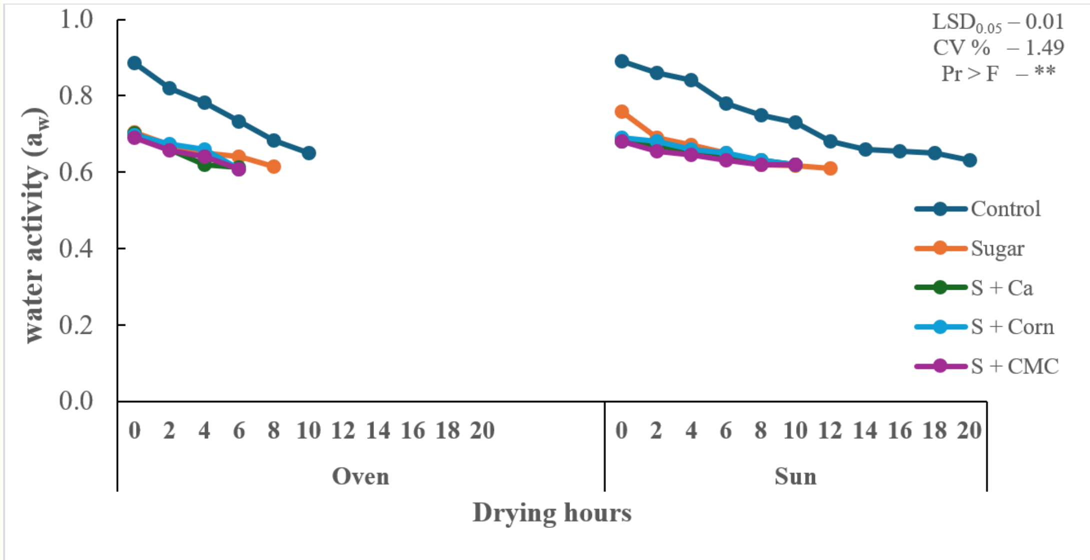

Figure 1: Effect of different drying methods and thickening agents on drying time (hours) of tamarind leather during drying processes. Con. = control (tamarind only), Sugar = no thickening agent, S = sugar, Ca = cassava starch, Corn = corn starch, CMC = carboxymethyl cellulose

Treatment	Moisture content (%)			
	Day	Month		
	0	1	2	3
Drying Methods (DM)				
Oven	12.04 b	12.75 b	13.07 b	14.61 b
Sun	12.55 a	13.38 a	14.44 a	15.22 a
$LSD_{0.05}$	0.14	0.10	0.05	0.06
Thickening agents (T)				
Con.	21.56 a	22.95 a	24.66 a	27.40 a
Sugar	11.20 b	11.66 b	12.74 b	13.56 b
S + Ca	8.13 e	9.01 d	9.13 e	9.94 e
S + Corn	9.62 d	10.03 c	10.23 d	11.01 d
S + CMC	10.95 c	11.67 b	12.02 c	12.67 c
$LSD_{0.05}$	0.23	0.17	0.08	0.10
Pr > F				
DM	**	**	**	**
T	**	**	**	**
DM × T	**	**	**	**
CV%	1.82	1.23	0.58	0.67

Table 1: Effect of different drying methods and thickening agents on moisture content (%) of tamarind leather.

In a column, means followed by the same letters are not significantly different at P < 0.05 by LSD test.

** = highly significant, Con. = control (tamarind only), Sugar = no thickening agent, S = sugar, Ca = cassava starch, Corn = corn starch, CMC = carboxymethyl cellulose, 0day = 7hrs after drying leather increased during the storage period due to high humidity in the environment. In comparison of drying methods for tamarind leather, the hot air oven drying had lower moisture content than sun drying due to the longer exposure to sun resulted to reabsorption of moisture [7]. There were decreasing trend in moisture content of tamarind leather ranging from 21.56 to 9.94% during 3 months. The leather without thickening agent (control) was the highest moisture content in all treatments. Among the different thickening agents, tamarind leather treated by cassava was the lowest moisture content. There was interaction between different drying methods and thickening agents on moisture content.

Total soluble solid of tamarind leather

The effect of different drying methods and thickening agents on the total soluble solid (°Brix) of tamarind leather is presented in (Table 2). There was highly significant difference on total soluble solid in all treatments by different drying methods and thickening agents. Total soluble solid was gradually decreased during storage period. The total soluble solid had higher values in hot air oven drying than that of sun drying. This may be due to shorter time at the high temperature reduced microbial growth and sugar degradation. It is similar with the finding of [7] who reported that the sun drying had lower TSS than hot air oven drying method. The reason may be the longer time during in the open drying resulted in the loss of sugars and acid favored to decrease in TSS.

The total soluble solid gradually decreased in all treatments along the storage period. [24] observed that TSS of guava leather was decreasing trend from the initial day of storage to 90 days after storage. In this study, total soluble solid in tamarind leather was decreasing range from 4.83 to 2.55 % during 3 months storage. In the comparison of thickening agents, the total soluble solid was the highest TSS (6.69%) in cassava followed by corn starch (6.63%). The reason may be due to the addition of starch based thickening agents and they retained total soluble solid by water-binding capacity [25]. There was interaction between drying methods and thickening agents on TSS.

Treatment	Total Soluble Solid (°Brix)									
	Day									
	0	7	14	21	28	42	56	70	84	91
Drying Methods (DM)										
Oven	6.23 a	5.50 a	5.08 a	5.00 a	4.92 a	4.22	3.75 a	3.4	3.12	2.85
Sun	5.19 b	4.71 b	4.63 b	4.51 b	4.43 b	4.31	3.48 b	3.3	3.03	2.81
$LSD_{0.05}$	0.37	0.31	0.29	0.23	0.28	0.33	0.20	0.39	0.26	0.30
Thickening agents (T)										
Con	4.83 b	4.68 c	4.58 ab	4.46 c	4.41 b	3.80 c	3.00 c	2.91 b	2.73 c	2.70
Sugar	5.06 b	4.50 bc	4.93 b	4.71 bc	4.68 ab	4.33 ab	3.96 a	3.91 a	3.34 a	3.04
S + Ca	6.69 a	5.44 ab	5.03 ab	4.50 ab	4.81 ab	4.18 bc	3.79 ab	3.26 b	3.25 ab	2.93
S + Corn	6.63 a	5.61 a	5.13 a	5.10 a	5.04 a	4.70 a	3.64 b	3.38 ab	3.15 ab	2.91
S + CMC	5.33 b	4.79 b	4.61 b	4.51 c	4.44 b	4.31 abc	3.71 ab	3.36 ab	2.89 bc	2.55
$LSD_{0.05}$	0.58	0.49	0.46	0.37	0.51	0.51	0.32	0.62	0.42	0.48
Pr > F										
DM	**	**	**	**	**	ns	**	ns	ns	ns
T	**	**	ns	**	ns	**	**	*	*	ns
DM × T	**	**	**	**	**	**	**	ns	ns	ns
CV%	9.97	9.14	9.29	7.56	9.36	11.77	8.60	17.82	13.32	17.03

Table 2: Effect of different drying methods and thickening agents on total soluble solid (°Brix) of tamarind leather.

In a column, means followed by the same letters are not significantly different at $P < 0.05$ by LSD test.

ns = non-significant * = significant ** = highly significant, Con. = control (tamarind only), Sugar = no thickening agent, S = sugar, Ca = cassava starch, Corn = corn starch, CMC = carboxymethyl cellulose, 0day = 7hr after drying

Total titratable acidity of tamarind leather

The effect of different drying methods and thickening agents on the total titratable acidity (TTA%) of tamarind leather is presented in (Table 3). There was highly significant difference on TTA in all treatments by different drying methods and thickening agents. Total titratable acidity was gradually increased during the storage period. In drying methods, hot air oven drying had the lowest TTA% and it was similar to [26] who reported that oven drying was lower TTA% than that of sun drying. The reasons might be removing water simultaneously reduced fruit sugar from the products by oxidation of reducing sugar that may increase TTA% [27]. The author [28] reported that the increased in titratable acid might be due to the breakdown of starch or carbohydrate into acids. The highest TTA% of only pulp (control) was found 1.73% at 3 months storage. This finding was similar to [29]. The lowest TTA% was observed in all leather treated by thickening agents. This might be due to the addition of thickening agent dilute the concentrations of TTA%. That means the addition of thickening agent will reduce the percentage of titrated acid levels in the tamarind paste [17]. There was interaction between thickening agents and drying methods on TTA %.

Treatment	Total Titratable acidity (%)									
					Day					
	0	7	14	21	28	42	56	70	84	91
Drying Methods (DM)										
Oven	0.29 b	0.30 b	0.32 b	0.37 b	0.38 b	0.41 b	0.39 b	0.43 b	0.45 b	0.48 b
Sun	0.35 a	0.40 a	0.47 a	0.48 a	0.48 a	0.52 a	0.57 a	0.58 a	0.59 a	0.60 a
$LSD_{0.05}$	0.05	0.04	0.02	0.03	0.06	0.04	0.06	0.02	0.03	0.09
Thickening agents (T)										
Con	1.12 a	1.20 a	1.37 a	1.44 a	1.47 a	1.55 a	1.62 a	1.67 a	1.68 a	1.73 a
Sugar	0.14 b	0.15 b	0.16 b	0.17 bc	0.17 b	0.19 bc	0.24 b	0.26 b	0.28 b	0.28 b
S + Ca	0.12 b	0.13 bc	0.14 bc	0.16 bc	0.19 b	0.22 b	0.22 bc	0.22 c	0.23 c	0.26 b
S + Corn	0.14 b	0.15 b	0.17 b	0.17 bc	0.17b	0.19 bc	0.21 bc	0.21 c	0.22 c	0.23 b
S + CMC	0.08 b	0.08 c	0.11 c	0.14 c	0.14 b	0.14 c	0.15 c	0.16 d	0.19 c	0.20 b
$LSD_{0.05}$	0.07	0.06	0.04	0.04	0.10	0.06	0.10	0.03	0.05	0.14
Pr > F										
DM	**	**	**	**	**	**	**	**	**	**
T	**	**	**	**	**	**	**	**	**	**
DM × T	ns	**	**	**	**	**	**	**	**	**
CV%	22.21	16.05	9.29	9.97	9.36	11.77	20.17	6.26	8.97	24.79

Table 3: Effect of different drying methods and thickening agents on total titratable acidity (TTA%) of tamarind leather.

In a column, means followed by the same letters are not significantly different at P < 0.05 by LSD test.

ns = non-significant ** = highly significant, Con. = control (tamarind only), Sugar = no thickening agent, S = sugar, Ca = cassava starch, Corn = corn starch, CMC = carboxymethyl cellulose, 0day = 7hr after drying

pH of tamarind leather

The effect of different drying method and thickening agents on the pH of tamarind leather is presented in (Table 4). There was highly significant difference on pH in all treatments by different drying methods and thickening agents. In this study, tamarind leather dried by hot air oven method was higher pH (lower acidity) than sun dried. This may be due to open sun drying, which involves prolonged exposure to light and air, potentially leading to partial fermentation or enzymatic activity. There were decreasing trend in pH during 3 months storage. In this study, pH in tamarind leather was decreasing trend ranging from 3.17 to 2.10 at 3 months after storage. It was similar to report of [30], the pH of leather fruit must be between 2.5 and 4.5 and pH was decreased during storage in blended guava-apple leather [31]. The pH of control (100% tamarind) was the lowest value among the treatments as well as CMC had the highest pH among the thickening agents. This might be due to the CMC is a sodium salt of a carboxylic acid (derived from cellulose). There was interaction between different drying methods and thickening agents on pH.

Treatment	pH									
	Day									
	0	7	14	21	28	42	56	70	84	91
Drying Methods (DM)										
Oven	3.63 a	3.43 a	3.30	3.15	3.08	2.91	2.76 a	2.63 a	2.43 a	2.18 a
Sun	3.40 b	3.29 b	3.23	3.14	3.10	2.82	2.39 b	2.25 b	2.15 b	2.04 b
$LSD_{0.05}$	0.08	0.10	0.09	0.09	0.09	0.17	0.11	0.16	0.14	0.10
Thickening agents (T)										
Con	3.17 e	2.93 d	2.64 c	2.36 d	2.30 d	1.98 c	1.56 c	1.54 b	1.51 c	1.41 d
Sugar	3.66 b	3.57 b	3.57 a	3.42 b	3.30 b	3.16 ab	2.70 b	2.53 a	2.33 b	2.10 c
S + Ca	3.33 d	3.34 c	3.27 b	3.19 c	3.15 bc	3.03 ab	2.79 b	2.70 a	2.57 a	2.55 a
S + Corn	3.49 c	3.23 c	3.19 b	3.14 c	3.12 c	2.90 b	2.76 b	2.67 a	2.56 a	2.14 c
S + CMC	3.89 a	3.72 a	3.66 a	3.61 a	3.61 a	3.27 a	3.04 a	2.76 a	2.48 ab	2.36 b
$LSD_{0.05}$	0.13	0.15	0.14	0.14	0.15	0.27	0.17	0.25	0.23	0.15
Pr>F										
DM	**	**	ns	ns	ns	ns	**	**	**	**
T	**	**	**	**	**	**	**	**	**	**
DM × T	**	ns	ns	ns	ns	ns	**	*	ns	**
CV%	3.69	4.38	4.29	4.57	4.57	9.05	20.17	9.81	9.71	7.07

Table 4: Effect of different drying methods and thickening agents on pH of tamarind leather.

In a column, means followed by the same letters are not significantly different at P < 0.05 by LSD test.

ns = non-significant * = significant ** = highly significant, Con. = control (tamarind only), Sugar = no thickening agent, S = sugar, Ca = cassava starch, Corn = corn starch, CMC = carboxymethyl cellulose, 0day = 7hr after drying

Ascorbic acid of tamarind leather

The effect of different drying methods and thickening agents on the ascorbic acid (mg/100g) of tamarind leather is presented in (Table 5). There was highly significant difference on ascorbic acid content in all treatments by different drying methods and thickening agents. Ascorbic acid gradually decreased during 3 months storage. Ascorbic acid content of guava mixed fruit leather showed significant decrease for increasing storage period and also affected by treatments [31]. In this study, oven drying was higher ascorbic acid than sun drying. This result observed that the longer the drying time, the less ascorbic acid. This may be due to temperature in the open sun and light exposure with the oxidation process during the drying process. It is similar with the finding of [7]. They stated that ascorbic acid of leather samples in oven drying is higher than that of sun drying. The pure tamarind leather (control) was the highest ascorbic acid due to the absence of sugar and thickening agents. All the fortified leathers have significant lesser ascorbic acid content compared to tamarind pulp [32]. The higher ascorbic acid content of tamarind leather treated by CMC was observed followed by cassava starch. This might be due to the binding water efficiency of CMC was more than others. There was interaction between different drying methods and thickening agents on ascorbic acid content.

Treatment	Ascorbic acid (mg/100g)			
	Day		Month	
	0	1	2	3
Drying Methods (DM)				
Oven	6.15 a	5.65 a	4.70 a	3.78 a
Sun	3.78 b	3.21 b	2.73 b	2.47 b
$LSD_{0.05}$	0.14	0.15	0.13	0.12
Thickening agents (T)				
Con.	7.81 a	6.81 a	5.89 a	4.12 a
Sugar	4.85 c	4.23 c	3.58 c	3.05 c
S + Ca	3.60 d	3.39 d	2.69 d	2.62 d
S + Corn	3.36 e	3.09 e	2.47 e	2.30 e
S + CMC	5.21 b	4.64 b	3.94 b	3.52 b
$LSD_{0.05}$	0.22	0.24	0.21	0.18
Pr>F				
DM	**	**	**	**
T	**	**	**	**
DM × T	**	**	**	**
CV%	4.41	5.33	5.58	5.73

Table 5: Effect of different drying methods and thickening agents on ascorbic acid (mg/100g) of tamarind leather.

In a column, means followed by the same letters are not significantly different at P < 0.05 by LSD test.

* = significant ** = highly significant, Con. = control (tamarind only), Sugar = no thickening agent, S = sugar, Ca = cassava starch, Corn = corn starch, CMC = carboxymethyl cellulose, 0day = 7hr after drying

Crude fiber of tamarind leather

Effect of different drying methods and thickening agents on crud fiber (%) of tamarind leather is presented in (Table 6). There was highly significant difference on crude fiber content in all treatments by different drying methods and thickening agents. All treatment showed a continuous decline in crude fiber content during 3 months storage while [33] who studied that the crude fiber content of mix-fruit leather was decreasing during the storage period. This might be due to the degradation of hemicelluloses and other structural polysaccharides during storage. In this study, hot air oven drying of tamarind leather was higher crude fiber content than sun dried. The reason may be due to the controlled and elevated temperature of hot air oven drying, which facilitates rapid removal of moisture and minimizes enzymatic and degradation of fiber components. The control (100% tamarind pulp) was the highest fiber content of 2.67% and the lowest one was 0.80 % in the corn starch leather. The increase in tamarind pulps, the more the fiber content of tamarind leathers was observed [34]. Among the thickening agents, CMC was the higher crude fiber than the cassava starch due to CMC is a modified cellulose polymer. There was interaction between different drying methods and thickening agents on crude fiber.

Treatment	Crude fiber (%)			
	Day		Month	
	0	1	2	3
Drying Methods (DM)				
Oven	1.93 a	1.24 a	0.81 a	0.61 a
Sun	1.05 b	0.90 b	0.61 b	0.46 b
$LSD_{0.05}$	0.28	0.03	0.02	0.02
Thickening agents (T)				
Con.	2.76 a	2.45 a	1.42 a	0.90 a
Sugar	0.94 d	0.58 d	0.44 d	0.31 d
S + Ca	1.29 c	0.80 c	0.49 c	0.40 c
S + Corn	0.80 e	0.62 d	0.39 e	0.26 e
S + CMC	1.68 b	0.90 b	0.83 b	0.80 b
$LSD_{0.05}$	0.04	0.05	0.03	0.04
Pr>F				
DM	**	**	**	**
T	**	**	**	**
DM × T	**	**	**	*
CV%	2.89	4.46	4.01	6.40

Table 6: Effect of different drying methods and thickening agents on crude fiber (%) of tamarind leather.

In a column, means followed by the same letters are not significantly different at P < 0.05 by LSD test.

* = significant ** = highly significant, Con. = control (tamarind only), Sugar = no thickening agent, S = sugar, Ca = cassava starch, Corn = corn starch, CMC = carboxymethyl cellulose, 0day = 7hrs after drying

Microbial population

Effect of different drying methods and thickening agents on microbial population (cfu/g) of tamarind leather is presented in (Table 7). The initial microbial analysis at 0 day to 7 days showed un-detectable levels of yeast and mold counts in all treatments at room temperature while yeast and mold counts were not detected in all leathers treated by thickening agents at 3 months storage. The authors [30] reported that microbial growth was inhibited by moisture content that was less than 15% with low pH. The highest total microbial population (cfu/g) was found in dried tamarind leather by open sun drying method due to exposure to environmental contaminants, dust, insects, and temperature fluctuation, which may enhance microbial growth. The microbial population of leather by the use of cassava starch and only sugar treatment dried by hot air oven was not detected till 3 months. The lowest one was found in hot air oven drying method by the use of cassava starch followed by CMC treatment (3.3×10^3 cfu/g). The highest microbial population (5×10^3 cfu/g) was observed in the corn starch. Similar result, [35] who reported that the total viable count of bacteria, yeast, and mold should be fewer than 1×10^4 cfu/ml that is acceptable level for fruit leather products.

Treatment		Yeast and mold count (cfu/g)	
Drying methods	**Thickening agents**	**0 day**	**3 months**
Oven	Con.	ND	1.6×10^3
	Sugar	ND	ND
	S + Ca	ND	ND
	S + Corn	ND	5×10^3
	S + CMC	ND	3.3×10^3
Sun	Con.	ND	2.1×10^3
	Sugar	ND	2×10^3
	S + Ca	ND	2.6×10^3
	S + Corn	ND	8.6×10^3
	S + CMC	ND	6×10^3

Table 7: Effect of different drying methods and thickening agents on yeast and mold count (cfu/g) of tamarind leather.

Con. = control (tamarind only), Sugar = no thickening agent, S = sugar, Ca = cassava starch, Corn = corn starch, CMC = carboxymethyl cellulose, 0day = 7hr after drying, ND = not detected

Redness (a*) value of tamarind leather

The effect of different drying methods and thickening agents on the redness (a*) of tamarind leather is presented in (Table 8). There was highly significant difference on redness value in all treatments by different drying methods and thickening agents. The redness (a*) value of tamarind leather showed an increasing trend during 3 months of storage. Oven drying exhibited a gradual increase in redness from 4.96 to 8.09 during storage. Both the drying method and the thickening agents had highly significant effects on redness (a*) at 91 days. Among the drying methods, oven-dried tamarind leather had the highest a* value (8.09) at 91 days. In contrast, the control sample (100% tamarind) showed a decrease in redness (a*) over the storage period. It is similar to the finding of [36] who reported that the redness (a*) of leather decreased throughout the storage. Other treatments with thickening agents showed an increasing trend in redness during storage. Among these, cassava treated leathers exhibited the highest a* value (10.65) at 91 days, followed by corn starch treatment. There was interaction between different drying methods and thickening agents on redness value.

Treatment	Redness (a*)									
	Day									
	0	7	14	21	28	42	56	70	84	91
Drying Methods (DM)										
Oven	4.96 a	5.34 a	5.57 a	5.46	5.63	5.63	6.11	7.43 a	7.79 a	8.09 a
Sun	4.67 a	4.66 b	4.77 b	4.91	6.35	6.35	6.55	6.81 a	6.91 b	6.97 b
$LSD_{0.05}$	0.62	0.66	0.76	0.67	0.92	0.92	0.66	0.72	0.78	0.79
Thickening agents (T)										
Con.	2.90 b	2.33 b	2.18 b	1.53 b	1.48 c	1.48 c	1.11 d	0.92 c	0.74 c	0.71 d
Sugar	5.50 a	5.61 a	5.87 a	6.07 a	6.70 b	6.70 b	7.21 bc	8.14 b	8.35 b	8.42 bc
S + Ca	5.17 a	5.48 a	5.91 a	6.11 a	8.20 a	8.20 a	8.28 a	9.77 a	10.36 a	10.65 a
S + Corn	5.50 a	5.91 a	6.34 a	6.39 a	7.10 ab	7.10 ab	8.12 ab	8.94 ab	9.25 ab	9.60 ab
S + CMC	5.03 a	5.66 a	5.56 a	5.82 a	6.46 b	6.46 b	6.93 c	7.82 b	8.04 b	8.28 c
$LSD_{0.05}$	2.50	4.24	3.91	3.22	3.68	2.79	4.09	1.14	1.04	1.25
Pr > F										
DM	ns	*	*	ns	ns	ns	ns	ns	*	**
T	**	**	**	**	**	**	**	**	**	**
DM × T	**	**	**	**	**	ns	**	**	**	**
CV%	19.90	20.42	22.69	19.51	14.55	23.28	18.92	16.44	16.19	15.55

Table 8: Effect of different drying methods and thickening agents on redness (a*) of tamarind leather.
In a column, means followed by the same letters are not significantly different at P < 0.05 by LSD test.
ns = non-significant * = significant ** = highly significant, Con. = control (tamarind only), Sugar = no thickening agent, S = sugar, Ca = cassava starch, Corn = corn starch, CMC = carboxymethyl cellulose, 0day = 7hr after drying.

Conclusion

Drying methods and thickening agents had significant effect on physiochemical properties of tamarind leather. The tamarind leather was dried by the open sun drying method which took 10 to 20 hours of drying time with water activity of 0.62. However, the hot air oven drying reached the same water activity (a_w) during 6 to 10 hours. The increase in moisture content and titratable acidity were observed during the storage, however, there is a decrease in pH, total soluble solid (TSS), ascorbic acid and crude fiber content of tamarind leather. The leather dried by open sun drying resulted in poor quality due to higher moisture content, less ascorbic acid and crude fiber. The hot air oven drying not only resulted shorter drying time but also minimized loss of crude fiber and ascorbic acid. The tamarind leather treated by carboxymethyl cellulose resulted the highest in pH, ascorbic acid and crude fiber contents among the thickening agents. However, it showed the lowest total soluble solids and the highest microbial population. This study revealed that tamarind leather dried by both drying methods using cassava starch resulted in higher total soluble solids, ascorbic acid, and crude fiber content than those treated with corn starch. Among the drying methods, the hot air oven drying method is more suitable with the use of carboxymethyl cellulose (CMC) is the best among the thickening agents, however, CMC is more expensive than cassava starch. In food safety aspects, there was no microbial population in tamarind leather using with cassava starch due to the lowest moisture content, however the acceptable level of microbial population was observed in CMC treated leather till 3 months. Therefore, cassava starch should be used for making of tamarind leather instead of CMC due to cheaper price.

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