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Evaluating the attributes of dried bananas using various Pre-treatments and drying methods

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Abstract: The quality of dried fruits plays an important role in consumer acceptance and desire to buy. Therefore, the research aims to study the effect of some pre-drying treatments and drying methods (sun and solar-controlled tunnel drying) on the quality of dried bananas. To achieve this goal, four pretreatment solutions before drying were used to enhance the physicochemical, phytochemical, and sensorial characteristics of banana slices: citric 1 % and ascorbic 1 %, sucrose 10 %, sodium bicolpate 0.5 %, and (lemon juice 5 % and acetic 0.5 %). In addition, two drying methods were applied, namely open sun drying (SD) and tunnel drying (TD). The dried slices were evaluated for moisture percentage, pH, total acidity, water activity, browning index, rehydration ratio, reducing sugar, total phenol, and antioxidant activity as well as sensory attributes. The results showed that the retention of acids content, ascorbic acid, total phenolics, and DPPH % in slice samples dried in TD was higher than that of SD. The browning index values in the TD samples were lower than those in the SD samples. Moreover, the tunnel-dried samples showed a higher rehydration ratio than the sun-dried samples. It is noted that the pretreatment solutions used have an important role in improving the final quality characteristics of dried banana slices. slices pretreated with (citric and ascorbic) and (lemon and acetic) showed the highest values of acidity, rehydration ratio, and total phenolics. The results of the sensory evaluation revealed a significant difference in the degrees of color and texture recorded for the slices pretreated with sodium bicolpate. Meanwhile, the rates of taste and odor were significantly higher for the sucrose-pretreated slices. Besides, the tunnel dryer can improve the drying kinetics, shorten the drying time, and maintain the quality of the dried slices.

Keywords: dried slices; tunnel; reducing sugar; ascorbic acid; sodium bicolpate

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1. Introduction

Bananas are one of the most popular fruits worldwide due to their great sensory acceptance and minimal cost. Bananas are seasonal fruits and have a short shelf-life and high-water activity. The moisture content in ripe bananas is 80% because it is very susceptible to deterioration. This causes significant losses after harvesting. The processing of bananas aims to produce other products and minimize waste [1]. Among the various processing methods, drying is a strategy process to reduce post-harvest losses [2]. The drying process decreases food's moisture level to a level that permits safe storage over an extended time while also preventing microbe development and minimizing microbial damage [3]. Furthermore, drying preserves items by reducing their bulk, weight, storage, transportation, and packaging expenses [4]. As well as, flavor and texture characteristics can be improved to create new products, including snacks, which may provide consumers with a healthy alternative to other commercial products like sweets [5]. The researchers have discussed various drying techniques typically employed in drying fruits [5–8].

Sun drying is a well-known process for drying agricultural commodities in tropical and subtropical areas. However, it has several drawbacks, including a lengthy drying period, nutritional loss, and contamination from dirt, dust, sand particles, and insects [9]. As a result, the quality of sun-dried items may suffer, failing to fulfill local and international requirements [10]. To solve these issues, other drying procedures must be used. As a result, using hot air in controlled cabinet drying by convective air is significantly more efficient and offers consistency and sanitation for commercial food drying procedures.

The new drying procedures should offer benefits including less energy consumption, high quality with reasonable cost, and low CO_2 emissions with improved environmental footprint. The choice of drying methods depends on several factors, such as food being dried, quality, energy consumption, and drying time. These drying methods all attempt to produce food products with superior qualities. Although many drying machines have been designed and tested in the food industry [11], industrial drying is a costly and energy-intensive process. Therefore, solar drying appears to be the best substitute approach [12]. Solar drying method does not require electricity and skilled labor. It is effective, sustainable, and economical. Furthermore, it creates jobs in the off-season in rural areas of developing countries. Additionally, it minimizes reliance on fossil fuels and their negative effects on the environment [12,13]. However, drying may result in flavor, color, nutrient, and antioxidant activity losses, as well as a reduction in bulk density and rehydration capacity of the final product [14]. Enzymatic and non-enzymatic processes that may occur during the drying of fresh plant tissues may result in significant changes in phytochemical composition [15]. Therefore, several pretreatments have been created to lessen negative alterations during drying [14,16,17]. The main objective of this study is to investigate the effect of pretreatments (citric and ascorbic, sucrose, sodium bisulfate, lemon juice, and acid) and drying methods (sun and solar-controlled tunnel drying) on the quality of dried bananas.

2. Materials and Methods

2.1. Banana samples

The Grand Nine variety bananas were purchased from the local fruits and vegetables market in Cairo, Egypt, in September 2021. Banana fruits were chosen for their uniform color and size, lack of pests, and physical damage. The samples were brought to the Laboratory of Food Science and Technology, Faculty of Agriculture, Al-Azhar University, Cairo, Egypt for processing before sun drying.

2.2. Drying methods

Sun drying and solar-controlled tunnel drying were the two drying techniques employed in the studies. In the sun drying, the treated banana slices were laid out on drying trays in a thin layer and exposed to the sun to dry the banana samples. On an elevated platform, the trays were put to dry in the sun. The high platform allows for ample airflow around the fruit, which was dried at an average temperature of 34°C. While the other method was using solar-controlled tunnel drying.

Figure 1 depicts the solar tunnel dryer assembly drawing. The solar tunnel setup with dimensions of 150×60×50 cm (latitude 30° 02' 30" N, longitude 31° 14' 07" E, and mean altitude above sea level 18 m) to ascertain the behavior of sliced bananas under solar drying. To maximize the impact of sun radiation on the tunnel method, it was oriented towards an east-west axis orientation. A 200 micron-thick plastic sheet made of polyethylene that is transparent was used to cover the tunnel. Banana slice halves were set on a single wire mesh tray that was 1.20×0.50 m in size and utilized for thin-layer solar drying. Sensors were used to measure the interior's temperature and relative humidity in the tunnel and outside. These sensors were installed in the tunnel dryer inlet, middle, and outlet points to continuously track the relative humidity and temperature for drying air. An appropriate Arduino device linked to a computer continuously recorded the relative humidity and temperature in the solar tunnel dryer throughout runs at 10-minute intervals.

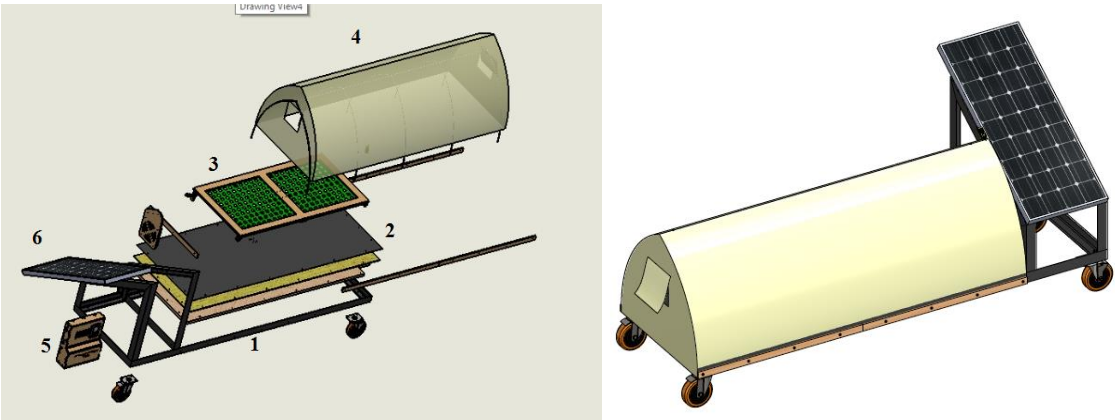


Figure 1. Assembly drawing of the solar tunnel dryer. Where: 1- steel structure, 2- tunnel floor, 3- drying tray, 4- reticular structure and plastic cover, 5- control box and 6- solar panel.

The solar tunnel drying is provided with a system for measuring, recording, and maintaining temperature and humidity is shown in Figure 2 on the right. A polycrystalline solar panel produces the required voltage in the morning when it is exposed to sunlight, producing a power of 40 watts with an average voltage of 18 volts, which is then used to charge an acid battery at a rate of 12 volts and 7 amps. The code that is tied to the processor memory instructs the processor to read the data output from the sensors, store them, and then send them to the screen for display at certain periods for each sensor. This is how the Arduino Mega 2560 board functions. The Tiny RTC DS1307 (Real Time Clock) board keeps the time and date to ensure that the values and readings are recorded together for accuracy, and restarting the Arduino board will reset the time and date. Three temperature and humidity sensors DHT22 collect humidity and temperature distributed inside and outside the tunnel to see the extent of the impact of insulation of the plastic tunnel and the amount of heat transferred, which are high-accuracy sensors. The VEML 6070 UV light sensor works to measure the level of ultraviolet rays, specifically from the sun's total radiation, because it increases damage to the product to be dried. The reading is displayed on the screen at an update and permutation rate of 0.25 seconds. The load cell sensor installed in the center of the tunnel floor measures the weight of the drying tray (known as "2350 grams") in addition to the product's weight spread within the tray. In every 10 minutes. The air agitating fan inside the tunnel works to expel the moisture-laden air and replace it with fresh air not to damage the product to be dried by relay, for only one minute to prevent all heat from leaking out. In each 10 minutes with the Micro SD Card Adapter, the current reading is taken from all sensors and recorded on the memory card with the time and date, which facilitates the process of follow-up.

In study was carried out Laboratory of Food Science and Technology, Faculty of Agriculture, Al-Azhar University, Cairo, Egypt. The weather was mainly sunny and dry throughout the drying experiments. The times of each experiment were 7:30 and 17:00. In all drying experiments, banana slices were placed in a single layer on a metal mesh tray within the tunnel for drying. Weight measurements were taken every 10 minutes. Afterward, dried slices were stored in low-density polyethylene pouches until the start of the analysis. For the sun drying method, samples of banana slices were placed on a tray near the dryer and dried concurrently under the same weather conditions to compare tunnel drying effectiveness with sun drying.

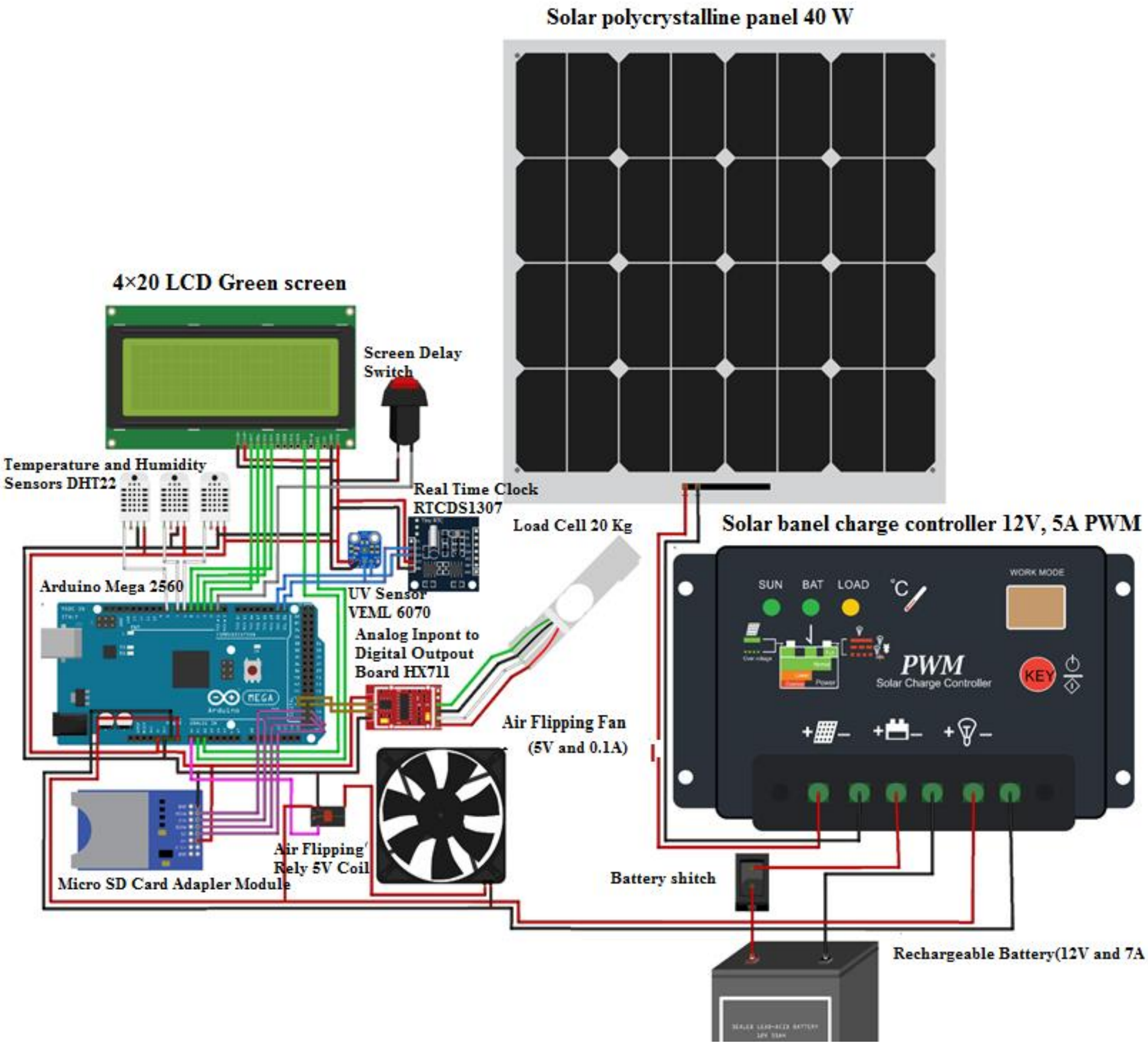


Figure 2. Various parts of embedded systems and their connection methods.

2.3. Preparation and Pretreatment on bananas before drying.

The banana fruits were peeled, weighed, and then cut into slices using a stainless-steel knife to a thickness of about 4 mm. The slices were pretreated using four different pretreated: citric 1% and ascorbic 1%; sucrose 10%; sodium bisulfate 0.5%; lemon juice 5% and acetic 0.5%; before drying; one sample was untreated and served as the control. The

Citric 1 % and ascorbic 1 % treatment was prepared using 20 g of citric acid and 20 g of ascorbic acid dissolved in 2000 mL of distilled water. To prepare a sucrose 10% treatment, 200 g of sucrose was dissolved in 2000 mL of distilled water. To prepare sodium bisulfate 0.5 % solution treatment, 10 g of sodium bisulfate was dissolved in 2000 mL of distilled water. Finally, lemon juice 5% and acetic 0.5% solution treatment was prepared using 10 g of acetic acid dissolved in 1900 mL distilled water, then 100 mL of lemon juice was added. High-purity solvents and chemicals were purchased from El-Gomhoria Company for Chemicals and Drugs, Cairo, Egypt. About 1000 g of banana slices were weighted for pretreatments for 10 minutes, after pretreatment they were subjected to drying. An untreated sample was used as a control to compare differences between all pretreatments. Then, each treatment was divided into two parts, the first to the open sun dryer and the second into the tunnel dryer.

2.4. Estimation of thermo-physical parameters

2.4.1. Initial moisture content

The oven was set at 105 °C to measure the initial moisture content till a consistent weight was obtained [18], and the equation that follows was employed to calculate:

$$\boldsymbol{M_{id} = \frac{W_m}{W_d} \times 100} \qquad (1)$$

Where: M_{id}: Moisture content on dry basis (%), W_m: Moisture content in sample (g) and W_d: Dry material content (g).

2.4.2. Moisture (M_t)

Every 30 minutes, the moisture percentage and wet basis (w.b.) percent were calculated as follows [19].

$$M_t = \frac{W_t - W_o\,(1 - m_o)}{W_t} \qquad (2)$$

Where: W_t: Sample weight (g) at any time, W_o: The fresh sample weight (g), and m_o: Initial moisture percent (w.b.%).

2.4.3. Moisture ratio

Moisture ratio (*MR*) can be measured utilizing the dried samples moisture percent at time t [20]**:**

$$MR = \frac{M_t - M_e}{M_i - M_e} \qquad (3)$$

Where: M_i: Initial moisture content (w.b.%), M_t: Moisture percent at any time during drying (w.b.%), and M_e: Equilibrium moisture (w.b.%).

2.4.4. Drying rate

Drying rate was calculated as follows:

$$MR = Drying\ rate = \frac{M_{t-dt} - M_t}{dt} = Kg(water)/hour \qquad (4)$$

Where: M_{t-dt} and M_t are the moisture contents at d_t and t times, respectively (d.b.), and d_t is the drying period (hour).

2.5. Analytical methods

2.5.1. pH value

The pH value was assessed by a pH meter (a Jenway 3505, UK) as described in reference [18].

2.5.2. Total acidity

Acidity content was determined according to titration method [21]. 50 mL of distilled water was added to 2 g of the ground slices sample. The mixture was stirred for 20 minutes, then three drops of phenolphthalein were added, and the titration was carried out by using NaOH solution 0.1 N, up to an endpoint of pH 8.1. The results were given as a percentage of malic acid (g per 100 g).

2.5.3. Water activity

Water activity (AW) of dried banana slices depended on pouring about 3 g within a sample AW cup. The AW, was measured in an Aqualab Model CX-2 meter at 25°C [22,23].

2.5.4. Browning index (Optical density (OD) measurement)

The browning index was assessed as absorbance density value using a UV-visible spectrophotometer as described in reference [24], where 2 g of dried slices were soaked in 20 mL of 60% ethanol and kept overnight, then filtered measuring absorbance (OD) at 440 nm by a UV-Visible spectrophotometer (Thermo Electron Company, Beverly, MA, USA)

2.5.5. Rehydration ratio

The rehydration ratio (RR) tests were performed after immersing five grams of dried banana slices in 300 mL of distilled water at ambient temperature; then the slices were drained and weighed. Based on the following equation, the amount of water rehydration was quantified as RR [25].

$$RR = M_{after\ soaking} / M_{before\ soaking} \quad (5)$$

Where M is the sample weight (g).

2.5.6. Reducing sugar

Reducing sugar content was determined by resolving 60 mg of dried slices in a 20 mL H_2SO_4 solution (1.5 M). The solution was heated at 100 °C for 20 minutes in the water bath. Afterward, it was cooled, neutralized using 12 mL of 10 % NaOH, filtered, and diluted to 60 mL with distilled water. Utilizing UV-Visible spectrophotometer (Thermo Electron Company, Beverly, MA, USA), reducing sugars were quantified at 540 nm [26]

2.5.7. Extraction and determination of total phenol and DPPH

Five gramss of dried banana slices were suspended in 40 mL of methanol (80 %) for 12 hours, centrifugation at 10.000× g for 20 minutes. The supernatant was collected, then filtrated using Whatman paper and used as crude extract [27]. For total phenolic (TPC) determination, 600 µL of crude extract and 600 µL of Folin-Ciocalteu reagent were combined with 4.80 mL of water and put in the dark for 90 minutes as described by Yu et al. [28]. The absorbance was read at

760 nm using a UV-Visible spectrophotometer (Thermo Electron Company, Beverly, MA, USA), and the TPC is given in mg GA /kg.

To determine the DPPH radical scavenging activity, 100 µL of the crude extract was added to 100 µL of the DPPH solution (0.2 mM). The combination was maintained at room temperature for one hour [29]. At 517 nm, the absorbance was recorded by UV-Visible spectrophotometer (Thermo Electron Company, Beverly, MA, USA), and the DPPH was calculated as a percentage.

2.6. Sensory evaluation

The dried banana slice samples were served to a sensory panel, which consisted of twenty staff members of Department of Food Sciences and Technology, Faculty of Agriculture, Al-Azhar University, and ten staff members of the Agriculture Constructer Engineering and Environmental Control Department, Faculty of Agriculture Engineering, Al-Azhar University. The samples were assessed for sensory attributes of color, odor, taste, texture, and overall acceptability. The evaluation used a nine-point hedonic test scale, as reference [30] explained.

2.7. Cost analysis

The results were calculated using the following formula: dryer hourly expenses based on the fixed and variable costs of the dryer [31].

$$C = \frac{P}{h}\left(\frac{1}{a} + \frac{i}{2} + t + r\right) + (W.e) + \frac{m}{200} \qquad (6)$$

Where: **C** = Dryer hourly cost, L.E. /h, P =Price of dryer, L.E., =800 L.E, h = Yearly working hours, which were assumed in the present work to be:(300 day/year x 1 period/day x 8 h/period = 2400 h/year), a = Life expectancy of machine, about (10 Year), i = Interest rate/Year. (The bank interest in Egypt), which was about 14%, t = Taxes and overheads ratio, which is assumed in the present work to be 20 %, r= Repair and maintenance ratio, which is assumed in the present work to be 10%., W = Power of dryer (kW), e = Hourly cost/kW. h, (0.0L.E./kW. h), m = The monthly average wage, L.E., (2400 L.E), imposes that there are 20 dryers becomes (120 L.E./man. dryer, month), 200 = The monthly average working hours.

$$Cost\,\frac{L.E}{(Kg_{\ dried\ product})} = \frac{Dryer\ hourly\ cost(\frac{L.E}{h})}{Dryer\ productivity(\frac{kg_{dried\ product}}{h})} \qquad (7)$$

2.8. Statistical analysis

The mean values and standard error were used to express the results. Every analysis assay was completed in triplicate. The mean values were subjected to evaluation using two-way analysis of variance (ANOVA) to check for significant differences ($p < 0.05$) by SPSS (version 22).

3. Results

Variations in the tunnel dryer outside and inside air temperature and relative humidity during experiments are shown in Figure 3. During the drying experiment, the daily mean values of in and out of the tunnel air temperature and relative humidity variations are from 39.4 to 54.5 °C, 28.1 to 36.9 °C, and 31.6 to 40.2 %, 41.5 to 48.7 %, respectively. The ambient air temperature in and out of the tunnel dryer reached the maximum between 11:00 and 14:00. This was when the relative humidity was at its lowest levels. It was found that the drying temperature in the tunnel dryer was higher than out temperature. In contrast, the tunnel dryer's relative humidity was lower than the relative humidity. There were significant differences between the values of the temperature and relative humidity. During the experimental time, these values were about 11.3 to 17.6 °C and 8.5 to 9.9 %. This indicates that the rate of drying in the tunnel drying will be higher than sun drying.

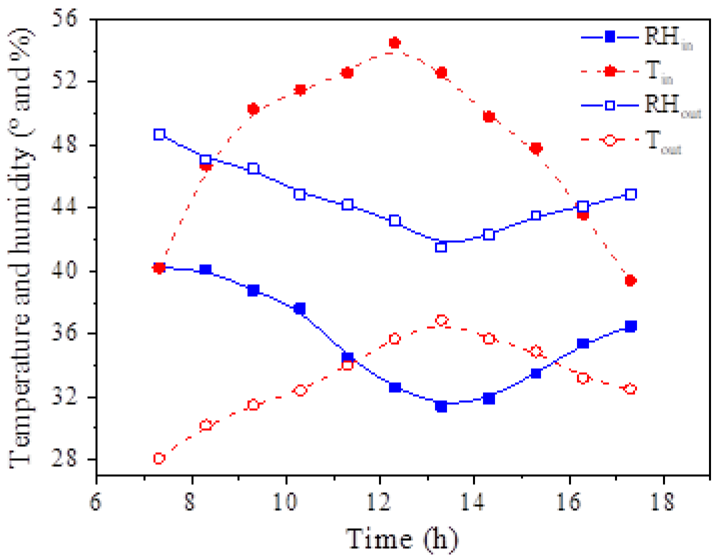
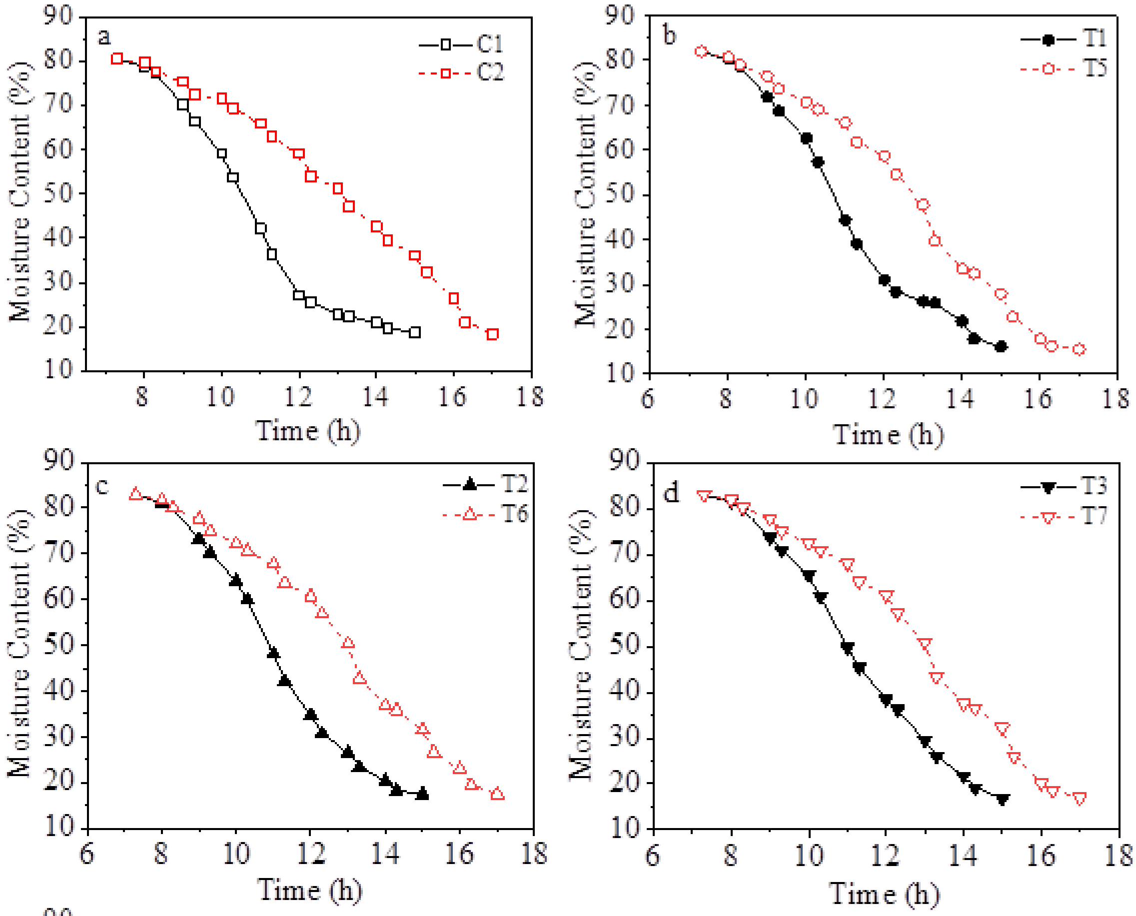


Figure 3. Changes in ambient temperature (°C) and relative humidity (%) with the drying hours for a typical day of September 2021.

The results of moisture contents for dried banana slices by open sun-drying were compared with those obtained by tunnel dryer under different pretreatments solutions, which are presented in Figure 4. There was a finding that the fresh slices had moisture of 80.4 %. This value is decreased exponentially with the increasing duration of drying time. The tunnel dryer had the most effect on the moisture content of the banana slices than open sun drying.



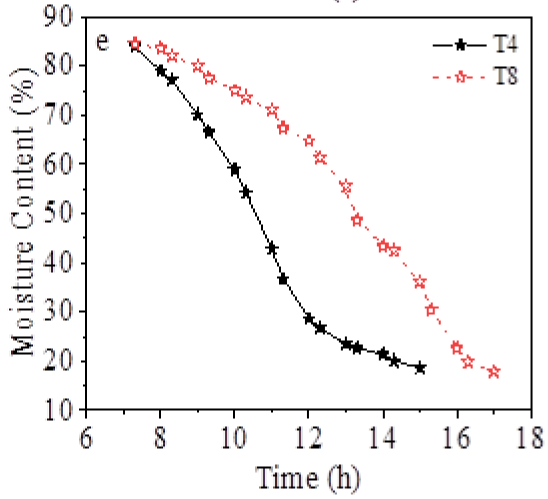


Figure 4. Variations in moisture percent over time during a typical experimental run during the solar drying of banana slices. (a) C1: Control Tunnel and C2: Control Sun, (b) T1: Sucrose Tunnel and T5: Sucrose Sun, (c) T2: Sodium bisulphate Tunnel and T6: Sodium bisul-

The content of moisture in the control tunnel (C1) reached 18.6 % (w.b.) in 8 hours of drying, though it needs 10 hours of drying to reduce the moisture content to 18.3 % (w.b.) in the control sun (C2). The lower drying time of banana slices inside the tunnel dryer may be because slices in the dryer received a collector's energy and incidental sun radiation. Meanwhile, the sample in open sun drying received the energy from the incident radiation only and lost energy that is significant for the environment. The slices treated with sucrose dried in a tunnel dryer had the lowest moisture percent (15.5 %), which might be related to the plasma and some moisture loss in the sample. The product is a consequence of the immersion process in these solutions, which shortened the time spent in the drying processes in the tunnel drier.

Also, Figure 4 displays the relationship between moisture content and drying rate for banana slices in the tunnel dryer and open sun. These curves do not have a constant rate drying phase, and all of the drying operations in the drying of the samples took place during the falling-rate drying phase. The drying rate is reduced with increased drying time and decreased moisture percent. These outcomes concurred with the findings of [32] for prickly pear peel and [8] for grape, carrot, and okra.

According to the results, the best moisture ratio is tunnel drying from sun drying (Figure 5). For example, after 6 drying hours' time, moisture ratio in the tunnel (C1) (0.2438) and sun drying (C2) (0.62079), the minimum value of the MR is equal to 0.1965, which corresponds to (C1).

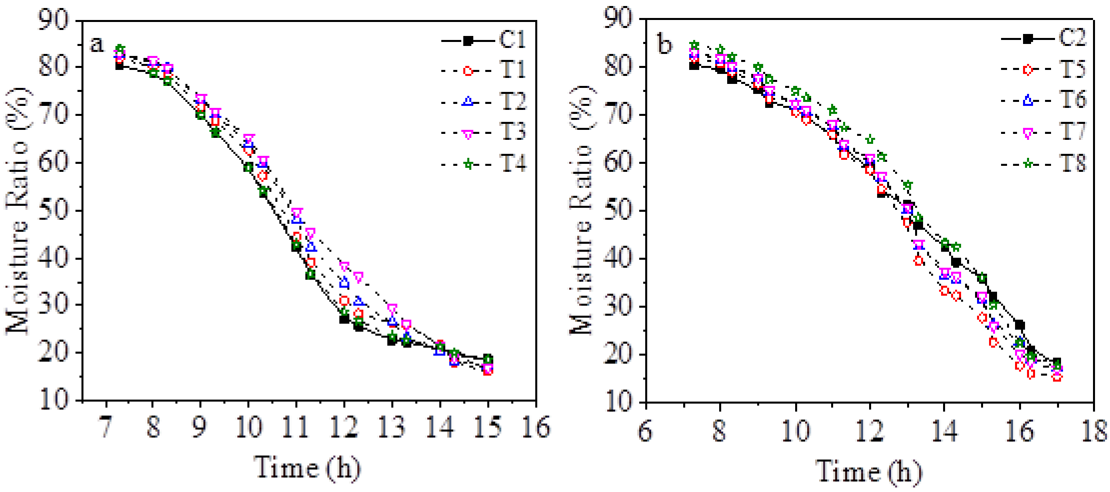


Figure 5. Moisture ratio vs Time (h) curves. (a) C1: Control Tunnel, T1: Sucrose Tunnel, T2: Sodium bisulfate Tunnel, T3: Ascorbic and citric Tunnel, T4: Lemon juice and Acetic Tunnel, (b) C2: Control Sun, T5: Sucrose Sun, and T6: Sodium bisulphate Sun, and T7: Ascorbic and citric Sun, and T8: Lemon juice and Acetic Sun.

The drying rate versus drying time, shows the presence of a falling drying rate period, which is enormously influenced by the drying air temperature. A higher drying air temperature produces a higher moisture loss and a consequently weak drying time. This is mainly due to the acceleration of the water migration inside the turmeric due to increased heat air supply to the product (Figure 6).

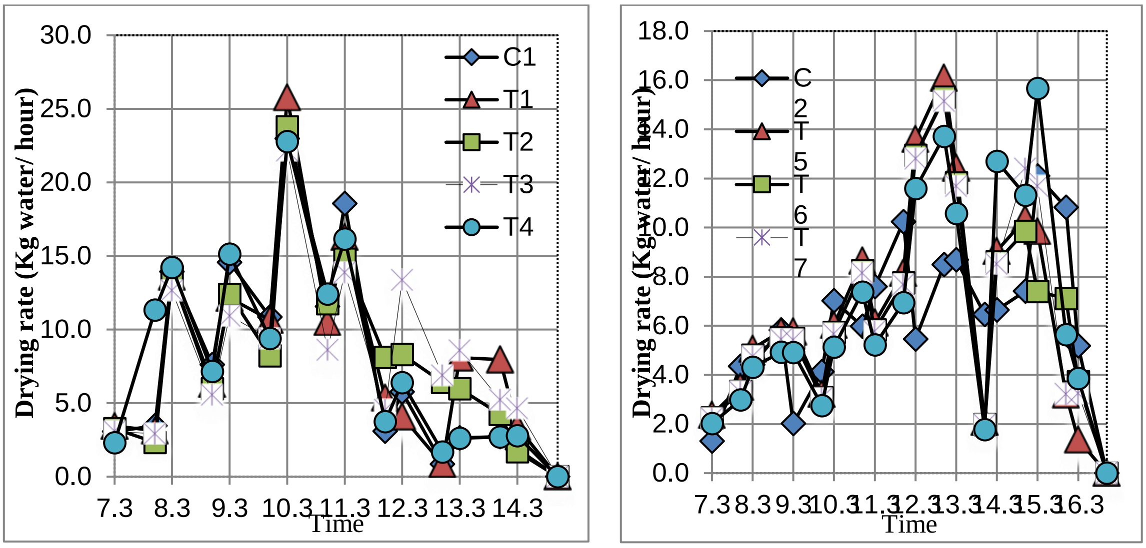


Figure 6. Drying rate (g water/ h) over Time (h) curves. (a) C1: Control Tunnel, T1: Sucrose Tunnel, T2: Sodium bisulphate Tunnel, T3: Ascorbic and citric Tunnel, T4: Lemon juice and Acetic Tunnel, (b) C2: Control Sun, T5: Sucrose Sun, and T6: Sodium bisulphate Sun, and T7: Ascorbic and citric Sun, and T8: Lemon juice and Acetic Sun.

The results on the effects of pretreatments and drying methods on the physicochemical properties of dried slices are presented in Table 1. Obviously, no significant differences between the two drying methods (sun and tunnel) were observed in pH values. As opposed to that, no notable variations between pretreatments were observed except for those samples treated with citric and ascorbic acids. The pH value for fresh Bananas was 5.86, which decreased after drying for all slice samples. The samples treated with citric and ascorbic acids had the lowest significant pH values (4.59 for TD and 4.66 for SD). In contrast, other samples were close to each other, varying from 5.33 to 5.78 with no significant differences. These findings align with those discussed in the references [33,34].

The acidity content of fresh Bananas was 0.47 %, which increased in the dried slices (Table 1). The highest acidity contents were found in dried slices treated with citric and ascorbic acid (1.08 and 0.99 %), followed by the sample treated with lemon and acetic acid (0.98 and 0.96 %) with non-significant differences between them ($p<0.05$). For other samples, total acidity contents were close, with no statistically significant different results between these samples. As opposed to that, significant differences were found between these samples and samples treated with citric and ascorbic acid, lemon and acetic acid. These findings show that utilizing citric and ascorbic, lemon, and acetic acid before the treatments raised the acidity number, agreeing with references [33-35].

Table 1. Effect of some pretreatments and drying methods on physicochemical properties of dried banana slices.

Parameters	Fresh banana	Drying methods	Treatments				
			Control	Citric and ascorbic	Sucrose	Sodium bisulfate	Lemon and acetic
pH	5.86	SD	5.78^{a} ±0.14	4.66^{b} ±0.11	5.76^{a} ±0.16	5.73^{a} ±0.17	5.35^{a} ±0.00
		TD	5.58^{a} ±0.17	4.59^{b} ±0.08	5.71^{a} ±0.14	5.69^{a} ±0.17	5.33^{a} ±0.16
Acidity (%) as malic	0.47	SD	0.50^{b} ±0.05	1.08^{a} ±0.11	0.53^{b} ±0.04	0.59^{b} ±0.02	0.98^{a} ±0.00
		TD	0.55^{b} ±0.11	0.99^{a} ±0.10	0.56^{b} ±0.04	0.57^{b} ±0.05	0.96^{a} ±0.08
Water activ-ity(a_w)	0.972	SD	0.692^{a} ±0.17	0.675^{a} ±0.28	0.652^{a} ±0.11	0.668^{a} ±0.23	0.658^{a} ±0.11
		TD	0.695^{a} ±0.00	0.672^{a} ±0.00	0.658^{a} ±0.00	0.670^{a} ±0.00	0.656^{a} ±0.00
Browning index (O.D)	0.25	SD	0.85^{a} ±0.28	0.60^{c} ±0.34	0.81^{ab} ±0.11	0.56^{c} ±0.17	0.69^{bc} ±0.23
		TD	0.79^{a} ±0.07	0.61^{bc} ±0.06	0.66^{b} ±0.09	0.50^{c} ±0.03	0.65^{b} ±0.08
Rehydra-tion ratio	-----	SD	2.34^{b} ±0.06	2.94^{a} ±0.08	2.43^{b} ±0.04	2.45^{b} ±0.05	2.92^{a} ±0.06
		TD	2.43^{b} ±0.10	3.12^{a} ±0.11	2.54^{b} ±0.08	2.86^{a} ±0.10	3.08^{a} ±0.07

Each mean value within identical letters on the identical row is significantly different at $p < 0.05$.
SD: sun drying and TD: tunnel dryer.

High quantities of moisture are present (80.4 %); they corroborate the high-water activity (aw) of the fresh banana (0.972). Dried bananas' water activity (AW) ranged from 0.652 to 0.695 (Table 1). It was observed that the highest water activity (0.695) was found for the control sample on the tunnel dryer. The decrease in aw minimizes degradation reactions and microbial growth, which helps preserve and lengthening the fruit's shelf-life [36].

The browning index for fresh banana was 0.25 and it increased in dried banana slices and reached 0.60, 0.81, 0.56, and 0.69 for treatments with citric and ascorbic, sucrose, sodium bisulfate, lemon and acetic, respectively with the sun-drying method. The same treatments in tunnel dryer reached 0.61, 0.66, 0.50 and 0.65 compared to control which showed the highest browning 0.85 for SD and 0.79 for TD with a significant difference between treatments. These results show that they are excellent in retaining white color after drying by treating banana slices with sodium bisulfate, citric and ascorbic acid, respectively. Anti-browning and antioxidant activities of bisulfate, ascorbic and citric acid might be the reason. Sulfate is widely used as a food preservative to inhibit oxidation either by oxygen or enzymes. These observations agree with the results reported in reference [37].

Rehydration ratio (RR) is one of the important indicators for the qualities of dried fruits and vegetables. The higher rehydration ratio values indicates these crops' quality [38]. A noticeable difference was found upon rehydration ratio from pretreatments impact, where citric and ascorbic acids, lemon and acetic acid had the highest values compared to other treatments (Table 1). In addition, a noteworthy difference was observed in the dried samples rehydration ratio by SD and TD, and the TD had the highest rehydration ratio. It could be revealed that the rehydration ratio ranged from 2.34 to 3.12. The highest rehydration ratio (3.12) was noticed for samples treated with citric and ascorbic on a tunnel dryer while the lowest ratio was 2.34 recorded for control samples on sun drying. Rehydration ratio changed from 2.34 to 2.94 for sun and from 2.43 to 3.12 for tunnel drying, respectively. An increased rehydration ratio in tunnel dried banana slices can be used to explain why fewer physical and chemical changes happened by tunnel drier is faster and more uniform. However, various irreversible physical and chemical changes occur as a result of drying, and the solutes that leak from damaged cells move to the surface and form a crust, resulting in a relatively closed surface structure [39]. Additionally, it can be noted that samples dried by tunnel rather than sun had higher rehydration capacities due to their porous structures.

Finally, there was no significant difference between drying methods for pH, acidity, water activity, browning index and rehydration ratio, except sample treated with sodium bisulfate which showed a meaningful difference between drying methods for rehydration ratio. From the results in Table 2, the highest reducing sugar content was found in dried banana slices with sucrose (21.25 for TD and 21.22 for SD on a dry weight basis). As opposed to that, the lowest reducing sugar content was recorded for citric and ascorbic acid treatments (19.72 for SD and 19.75 % in TD). The dried banana slices showed reducing in sugar concentration similar to that observed by Takougnadi et al. [40]. These compositional variations are mostly caused by the fruits maturity level at the time of drying, and too much reducing sugar might cause non-enzymatic browning [41]. There was no significant difference between SD and TD on reducing sugar of the dried banana slices and the effect was similar, but a significant difference was observed from pretreatments where sucrose treatments had the highest values (21.22 for SD and 21.25 for TD). Also, the losses of the reducing sugar content in SD and TD dried banana slices might be attributed to the drying time of this method (10 and 8 hours), which may result in the browning reaction, which creates distinctive brown pigments, when certain components react with one another [42]. Furthermore, Millard reaction may have occurred in dried banana slices produced by sun-drying which involve the binding of reducing sugars with amino acids, eventually leading to a loss in the total sugars especially the reducing sugars [43].

The phenolic compounds' content in fruits and vegetables depends on the cultivar, growing condition, storage and transport conditions, and processing technology [44]. The total phenolic contents (TPC) as affected by drying techniques and pretreatments solutions are presented in Table 2. TPC in fresh banana was 96.91 mg/kg, while it ranged from 99.09 to 115.90 mg/kg for dried slices. From Table 2, the impact of drying methods on TPC was statistically significant ($p < 0.05$). The sample pretreated with citric and ascorbic acid had the highest TPC ($p < 0.05$), while the control samples had the lowest TPC. The TPC was higher in tunnel-dried samples than in slices dried in the sun. These results might be attributed to increased enzymatic degradation by polyphenol oxidase because direct and mixed mode dryers dried materials more slowly than tunnel dryers, with more enzymatic reactions.

Table 2. Effect of pretreatments and drying methods on reducing sugar, total phenolic, ascorbic acid and antioxidant activity

Parameters	Drying methods	Fresh	Treatment				
			Control	Citric and ascorbic	Sucrose	Sodium bisulfate	Lemon and acetic
Reducing sugar	SD	16.08	19.98^{a} ±0.57	19.72^{a} ±0.46	21.02^{a} ±0.40	19.90^{a} ±0.51	19.75^{a} ±0.69
	TD		20.02^{a} ±0.69	19.75^{a} ±0.51	21.05^{a} ±0.46	19.96^{a} ±0.75	19.80^{a} ±0.63
Total phenolic mg/kg	SD	96.91	99.09^{c} ± 1.73	113.85^{a} ± 2.88	102.37^{c} ± 1.15	111.98^{a} ± 0.86	106.87^{b} ± 2.30
	TD		101.76^{d} ± 0.43	115.90^{a} ± 0.46	105.84^{c} ± 0.75	109.69^{b} ± 1.03	108.52^{b} ± 1.61
Ascorbic acid (%)	SD	44.87	65.14^{d} ± 0.20	80.23^{ab} ± 0.23	74.86^{c} ± 0.46	81.16^{a} ± 0.40	79.45^{b} ± 0.46
	TD		73.21^{e} ± 0.23	83.63^{b} ± 0.02	78.13^{d} ± 0.51	84.95^{a} ± 0.17	81.35^{c} ± 0.40
DPPH (%)	SD	60.22	83.03^{c} ± 0.57	85.00^{ab} ± 0.69	85.57^{a} ± 0.46	85.06^{ab} ± 0.86	84.11^{b} ± 0.75
	TD		83.28^{c} ± 0.51	86.61^{a} ± 0.57	86.03^{ab} ± 0.44	85.73^{ab} ± 0.69	84.34^{b} ± 0.63

Each mean value, within identical letters on the identical row is significantly different of $p < 0.05$.
SD: sun drying and TD: tunnel dryer.

A significant difference between treatments was observed in ascorbic acid content (Table 2). The highest ascorbic acid content was detected with sodium bisulfate treatments, while the lowest content was observed for the control treatments. The treatments with sodium bisulfate, as well as citric and ascorbic, were the highest for preserving ascorbic acid from heat breakage, while the rest of the dried treatments were close to each other in both treatments. In addition, using a tunnel for drying prevented ascorbic acid from breaking down and minimized its loss throughout the drying process, which is a benefit of using tunnel for drying. These findings align with Alam et al.'s reports [34]. Also, from the table, the tunnel dried samples showed a higher ascorbic acid content than sun dried samples, and this might be because of the fast drying process in tunnel dryer. The greater loss of ascorbic acid in sun-dried samples might be related to the time of drying process [45]. Where, the ascorbic acid was destroyed, during the process of dehydration, it was oxidized to dehydroascorbic acid. Following reactions like decarboxylation and cyclization, 3-hydroxy-2-pyrone and 2-furoic acid were finally produced.

Furthermore, all dried banana slices showed a high content of antioxidants (83.03 to 86.61 %) compared to fresh banana (60.22 %). The increased antioxidant activity that was seen of dried bananas might correspond to the much higher phenolic and ascorbic acid contents. Additionally, the antioxidant capacity of sun-dried bananas was not as high as that of the tunnel-dried bananas, and this may be related to the greater decline in ascorbic acid and the overall amount of phenolic in the banana slices drying in the open sun. For the dried tunnel bananas, the retention of the antioxidant ranged from 83.28 to 86.61 %, compared 83.03 to 85.57 % for sun drying. Also, all pretreatments resulted in a higher antioxidant ($p < 0.05$) activity (from 84.11 to 86.61 %) as compared to control (83.03 and 83.28 %). This is explained by the increase in total phenolic and ascorbic acid upon drying. These results are roughly in accordance, since antioxidant activity completely depends on pigments like carotenoid and anthocyanin, ascorbic acid and overall phenolic content in the product [46,47]

- *Sensory evaluation*

The color, taste, odor, texture and overall acceptability scores for dried banana slices were evaluated and presented in Table 3. It might suggest that the results of the sensory attributes show that bananas dried in the tunnel dryer have the higher liking score for the most tested organoleptic characteristics compared to open sun-dried slices. The results showed that the highest ($p < 0.05$) color score was observed for dried treated with sodium bisulphate (9.0 for SD and 9.50 for TD), while the lowest ($p < 0.05$) was recorded for control (5.00 for SD and 6.00 for TD), whereas other dried slices ranged from 7.0 to 8.5 with significant differences between them. Tunnel dryer presented fewer color changes than the sun drying process. This also corresponds to the results of Elicin and Sacilik [48]. This darker color throughout the sun-drying process resulted from the fruit surfaces being exposed to solar radiation for longer. This might be because enzymatic browning is limited when drying at high temperatures in the beginning. However, high energy input may also lead to non-enzymatic browning after drying, which is why sample tunnel drying is superior to sun drying in terms of quality. At the beginning of drying, low temperatures keep the products surface moist longer than high temperatures, which encourages the enzymatic browning of the product. This is consistent with the findings of Pekke et al. [49].

On the other hand, the judging scores of taste property was recorded (5.25 to 8.0 for SD and 5.50-8.0 for TD slices. The highest ($p< 0.05$) taste score was recorded for slices treated with sucrose (8.0), while the lowest ($p< 0.05$) was recorded for lemon and acetic acid treatments (5.25 for SD and 5.50 for TD). For odor, the highest ($p< 0.05$) score was found in slices treated with sucrose (7.50 and 8.0), while the lowest ($p< 0.05$) was recorded for control samples (5.0 for SD and 5.80 for TD). The texture score was the highest significantly in slices treated with sodium bisulfate (8.0 for SD and 9.0 for TD) even if the lowest score was noted for control samples (5.0). The slices rated by sulfate and sucrose had overall acceptability more than other treatments.

Table 3. Effect of pretreatments and drying methods on organoleptic properties of dried banana slices

Sensory properties	**Drying methods**	**Treatment**				
		Control	**Citric + ascorbic**	**Sucrose**	**Sodium bisulfate**	**Lemon + acetic**
Color	SD	5.00^{d} ±0.06	8.50^{b} ±0.07	7.00^{c} ±0.05	9.00^{a} ±0.12	7.00^{c} ±0.11
	TD	6.00^{e} ±0.07	8.50^{b} ±0.12	8.00^{c} ±0.15	9.50^{a} ±0.12	7.00^{d} ±0.07
Taste	SD	6.00^{c} ±0.05	7.00^{b} ±0.07	8.00^{a} ±0.12	6.00^{c} ±0.06	5.25^{d} ±0.06
	TD	6.00^{c} ±0.10	7.00^{b} ±0.15	8.00^{a} ±0.20	6.00^{c} ±0.07	5.50^{d} ±0.12
Odor	SD	5.00^{d} ±0.05	6.50^{b} ±0.12	7.50^{a} ±0.12	6.50^{b} ±0.10	6.00^{c} ±0.07
	TD	5.80^{d} ±0.20	6.50^{c} ±0.07	8.00^{a} ±0.20	7.00^{b} ±0.18	6.00^{d} ±0.12
Texture	SD	5.00^{d} ±0.07	7.00^{b} ±0.20	7.00^{b} ±0.15	8.00^{a} ±0.25	6.50^{c} ±0.12
	TD	5.00^{d} ±0.12	7.00^{c} ±0.18	8.00^{b} ±0.18	9.00^{a} ±0.25	7.00^{c} ±0.19
Overall acceptability	SD	5.25^{c} ±0.20	7.25^{a} ±0.12	7.38^{a} ±0.09	7.38^{a} ±0.10	6.13^{b} ±0.03
	TD	5.75^{d} ±0.19	7.25^{b} ±0.06	8.00^{a} ±0.25	7.88^{a} ±0.22	6.38^{c} ±0.09

Each mean value within the identical letters on the identical row is significantly different at $p < 0.05$.
SD: sun drying and TD: tunnel dryer.

The taste rating is similarly lower, which may be related to the same effect of hardening and moisture loss. Banana slice sensory scores across the board may have decreased, which has led to a decline in the overall acceptability of sun-dried banana slices. Additionally, because of the lengthy drying duration necessity, sun drying degrades the nutritional value, texture, color, and taste of food. The most popular way for drying food is sun exposure. However, due to the prolonged drying time and temperature irregularities, this method causes serious harm, such as deteriorating the flavor, color, and nutritional value of the dry product, decreasing density and water absorption capacity, and shifting solutes from the internal part of the drying material to the surface. The ability of water to rehydrate itself as well as the mobility of the drying material is further negative impacts. Finally, the slices dried by tunnel dryer was superior in terms of all the characteristics, especially in color and texture property so they outperformed the slices dried by sun drying due to increasing the drying time (10 hrs) compared with drying time taken by tunnel dryer (8 hrs) as shown in Figure 7. A significant difference was observed in color, odor and texture at the probability $p<0.05$ level between treatments and drying methods.

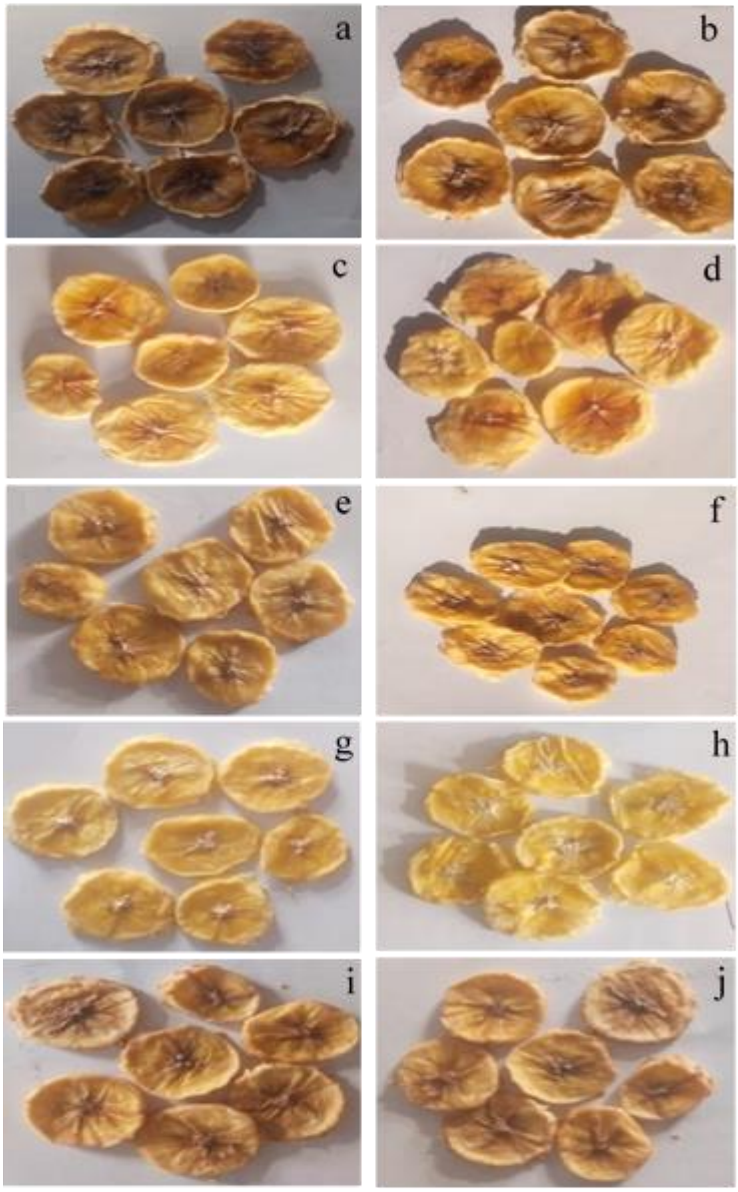


Figure 7. Effect of pretreatments and some drying methods on color values of dried banana slices: (a) Control (sun), (b) Control (tunnel), (c) Citric 1% + ascorbic 1% (sun), (d) Citric 1% + ascorbic 1% (tunnel), (e)

Sucrose 10% (sun), (f) Sucrose 10% (tunnel), (g) Sodium bisulfate 0.5% (sun), (h) Sodium bisulfate 0.5% (tunnel), (i) Lemon 5% + acetic 0.5% (sun), (j) Lemon 5% + acetic 0.5% (tunnel).

- *Costs analysis*

The operating cost (LE /h) for the convection dryer and the costs of kilogram dried product of banana slices was calculated by equation (6) and (7). The expenses were calculated using drying settings, resulting in a shorter drying time. The operating cost of tunnel dryer was 0.7551 LE/h and the kilogram of dried product was 11.4 LE/kg, while operating cost of sun drying was 0.6 LE/h and the kilogram of dried product was 11.3 LE/kg.

5. Conclusions

Effects of pretreatment solutions including citric and ascorbic, sucrose, sodium bisulphate, lemon juice and acetic as well as drying techniques, including sun drying (SD) and tunnel drying (TD) on the properties of dried banana slices were assessed. The outcomes showed that the TD is more closely matched to the drying curves than the SD method. TD would be a substitute drying method for obtaining products with a huge market and relatively high quality. In addition, applying pretreatment techniques already have a significant role in saving dried banana slices' final qualitative attributes and has enormous potential for use in the food industry.

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References

1. Amini Khoozani, A.; Birch, J.; Bekhit, A.E.D.A. Production, Application and Health Effects of Banana Pulp and Peel Flour in the Food Industry. *J. Food Sci. Technol.* **2019**, *56*, 548–559, doi:10.1007/S13197-018-03562-Z/TABLES/2.
2. Abe-Inge, V.; Agbenorhevi, J.K.; Kpodo, F.M.; Adzinyo, O.A. Effect of Different Drying Techniques on Quality Characteristics of African Palmyra Palm (Borassus Aethiopum) Fruit Flour. *Food Res.* **2018**, *2*, 331–339, doi:10.26656/FR.2017.2(4).050.
3. Doymaz, İ. Drying of Green Bean and Okra under Solar Energy. . *Chem. Ind. Chem. Eng. Quarterly/CICEQ* **2011**, *17*, 199-205.
4. Eric, W. C. C., Phui, Y. L., Lea, N. T., Suit, Y. E., Yuen, P. T., & Zhiew, C.W. Effects of Drying Method and Particle Size on the Antioxidant Properties of Leaves and Teas of Morus Alba, Lagerstroemia Speciosa and Thunbergia Laurifolia. *Chem. Ind. Chem. Eng. Q.* **2012**, *18*, 465-472.
5. Sehrawat, R.; Nema, P.K.; Kaur, B.P. Quality Evaluation and Drying Characteristics of Mango Cubes Dried Using Low-Pressure Superheated Steam, Vacuum and Hot Air Drying Methods. *LWT* **2018**, *92*, 548–555, doi:10.1016/J.LWT.2018.03.012.
6. Izli, N.; Izli, G.; Taskin, O. Impact of Different Drying Methods on the Drying Kinetics, Color, Total Phenolic Content and Antioxidant Capacity of Pineapple. *http://mc.manuscriptcentral.com/tcyt* **2018**, *16*, 213–221, doi:10.1080/19476337.2017.1381174.
7. Link, J.V.; Tribuzi, G.; Laurindo, J.B. Conductive Multi-Flash Drying of Mango Slices: Vacuum Pulse Conditions on Drying Rate and Product Properties. *J. Food Process. Preserv.* **2018**, *42*, e13440, doi:10.1111/JFPP.13440.
8. Abul-Fadl, M.M.; Ghanem, T.H.; EL-Badry, N.; Nasr, A. Effect of Puff Drying on Seedless Grape Fruits Quality Criteria Compared to Convective Air Drying. *Al-Azhar J. Agric. Res.* **2020**, *45*, 75–91, doi:10.21608/AJAR.2020.126645.
9. Folaranmi, J. Design, Construction and Testing of Simple Solar Maize Dryer. *Leonardo Electron. J. Pract. Technol.* **2008**, *1*, 122-130.
10. Ivanova, D., & Andonov, K. Analytical and Experimental Study of Combined Fruit and Vegetable Dryer. . *Energy Convers. Manag.* **2001**, *42*, 975-983.
11. Nemzer, B.; Vargas, L.; Xia, X.; Sintara, M.; Feng, H. Phytochemical and Physical Properties of Blueberries, Tart Cherries, Strawberries, and Cranberries as Affected by Different Drying Methods. *Food Chem.* **2018**, *262*, 242–250, doi:10.1016/J.FOODCHEM.2018.04.047.
12. Nabnean, S.; Janjai, S.; Thepa, S.; Sudaprasert, K.; Songprakorp, R.; Bala, B.K. Experimental Performance of a New Design of Solar Dryer for Drying Osmotically Dehydrated Cherry Tomatoes. *Renew. Energy* **2016**, *94*, 147–156, doi:10.1016/J.RENENE.2016.03.013.
13. Varalakshmi, K. Role of Conventional Energy in Rural Development in India: Feasibility Analysis of Solar Drying Technology. *Int. J. Energy Environ. Eng.* **2016**, *7*, 321–327, doi:10.1007/S40095-016-0210-8/TABLES/9.
14. Soomro, A. H., Miano, T. F., Marri, A., Kumar, D., Khaskheli, G. S., Arain, U. F., & Baloch, A.B. Application of Pretreatments on Banana Slices for Improving Drying Characteristics. *Food Sci. Qual. Manag.* **2020**, 35-41.
15. Capecka, E., Mareczek, A., & Leja, M. Antioxidant Activity of Fresh and Dry Herbs of Some Lamiaceae Species. . *Food Chem.* **2005**, *93*, 223-226.

16. Abano, E.E.; Sam-Amoah, L.K.; Owusu, J.; Engmann, F.N. Effects of Ascorbic Acid, Salt, Lemon Juice, and Honey on Drying Kinetics and Sensory Characteristic of Dried Mango. *Croat. J. food Sci. Technol.* **2013**, *5*, 1–10.
17. Deori, G. D., Langthasa, S., Hazarika, D. N., Goswami, R. K., & Kalita, M.K. Effect of Pretreatment on Quality of Minimally Processed Culinary Banana Cv. Kachkal (ABB Group). *J. Pharmacogn. Phytochem.* **2020**, *9*, 2256-2262.
18. Official methods of analysis of the association Official Methods of Analysis of the Association of Official Analytical Chemists International (20th Edition). *J. Assoc. Off. Agric. Chem.* **2016**, *Maryland,*.
19. Usub, T.; Lertsatitthanakorn, C.; Poomsa-ad, N.; Wiset, L.; Yang, L.; Siriamornpun, S. Experimental Performance of a Solar Tunnel Dryer for Drying Silkworm Pupae. *Biosyst. Eng.* **2008**, *101*, 209–216, doi:10.1016/J.BIOSYSTEMSENG.2008.06.011.
20. Karthikeyan, A.K.; Murugavelh, S. Thin Layer Drying Kinetics and Exergy Analysis of Turmeric (Curcuma Longa) in a Mixed Mode Forced Convection Solar Tunnel Dryer. *Renew. Energy* **2018**, *128*, 305–312, doi:10.1016/J.RENENE.2018.05.061.
21. Araújo, C. da S.; Macedo, L.L.; Vimercati, W.C.; Ferreira, A.; Prezotti, L.C.; Saraiva, S.H. Determination of PH and Acidity in Green Coffee Using Near-Infrared Spectroscopy and Multivariate Regression. *J. Sci. Food Agric.* **2020**, *100*, 2488–2493, doi:10.1002/JSFA.10270.
22. Lewicki, P.P.; Lukaszuk, A. CHANGES OF RHEOLOGICAL PROPERTIES OF APPLE TISSUE UNDERGOING CONVECTIVE DRYING. *http://dx.doi.org/10.1080/07373930008917733* **2007**, *18*, 707–722, doi:10.1080/07373930008917733.
23. Gabas, A.L.; Menegalli, F.C.; Ferrari, F.; Telis-Romero, J. INFLUENCE OF DRYING CONDITIONS ON THE RHEOLOGICAL PROPERTIES OF PRUNES. *http://dx.doi.org/10.1081/DRT-120005863* **2007**, *20*, 1485–1502, doi:10.1081/DRT-120005863.
24. Siddiqui, S.; Gehlot, R.; Arora, S.; Ahmed, N. Effects of Anti-Browning Pretreatments on Browning of Banana Pulp. *Int. J. Curr. Microbiol. Appl. Sci.* **2018**, *7*, 242–249, doi:10.20546/ijcmas.2018.704.027.
25. Dehghannya, J.; Kadkhodaei, S.; Heshmati, M.K.; Ghanbarzadeh, B. Ultrasound-Assisted Intensification of a Hybrid Intermittent Microwave - Hot Air Drying Process of Potato: Quality Aspects and Energy Consumption. *Ultrasonics* **2019**, *96*, 104–122, doi:10.1016/J.ULTRAS.2019.02.005.
26. Anjos, O.; Paula, V.; Delgado, T.; Estevinho, L. Influence of the Storage Conditions on the Quality of Bee Pollen. *Zemdirbyste* **2019**, *106*, 87–94, doi:10.13080/Z-A.2019.106.012.
27. Alshallash, K.S.; Abolaban, G.; Elhamamsy, S.M.; Zaghlool, A.; Nasr, A.; Nagib, A.; El-Hakim, A.F.A.; Zahra, A.A.; Hamdy, A.E.; Taha, I.M. Bee Pollen as a Functional Product – Chemical Constituents and Nutritional Properties. *J. Ecol. Eng.* **2023**, *24*, 173–183, doi:10.12911/22998993/156611.
28. Yu, G., Bei, J., Zhao, J., Li, Q., & Cheng, C. Modification of Carrot (Daucus Carota Linn. Var. Sativa Hoffm.) Pomace Insoluble Dietary Fiber with Complex Enzyme Method, Ultrafine Comminution, and High Hydrostatic Pressure. . *Food Chem.* **2018**, 333-340.
29. Akan, E., Yerlikaya, O., Akpinar, A., Karagozlu, C., Kinik, O., & Uysal, H.R. The Effect of Various Herbs and Packaging Material on Antioxidant Activity and Colour Parameters of Whey (Lor) Cheese. *Int. J. Dairy Technol.* **2021**, *74*, 554-563.
30. Gallali, Y.M.; Abujnah, Y.S.; Bannani, F.K. Preservation of Fruits and Vegetables Using Solar Drier: A Comparative Study of Natural and Solar Drying, III; Chemical Analysis and Sensory Evaluation Data of the Dried Samples (Grapes, Figs, Tomatoes and Onions). *Renew. Energy* **2000**, *19*, 203–212,

doi:10.1016/S0960-1481(99)00032-4.
31. Awady, M. N., Yehia, I., Ebaid, M. T., & Arif, E.M. Development and Theory of Rice Cleaner for Reduced Impurities and Losses. *Misr J. Ag. Eng* **2003**, *4*, 53–68.
32. Lahsasni, S.; Kouhila, M.; Mahrouz, M.; Idlimam, A.; Jamali, A. Thin Layer Convective Solar Drying and Mathematical Modeling of Prickly Pear Peel (Opuntia Ficus Indica). *Energy* **2004**, *29*, 211–224, doi:10.1016/J.ENERGY.2003.08.009.
33. Ferreira, T.H.B.; Freitas, M.L.F. Production, Physical, Chemical and Sensory Evaluation of Dried Banana (Musa Cavendish). *Emirates J. Food Agric.* **2019**, *31*, 102–108, doi:10.9755/EJFA.2019.V31.I2.1912.
34. Alam, M.; Afzal, M.; Ku Leuven, H.; Sarkar, A.; Hossain, M.A. Effect of Edible Coating on Functional Properties and Nutritional Compounds Retention of Air Dried Green Banana (Musa Sapientum L.) . *Artic. IOSR J. Environ. Sci. Toxicol. Food Technol.* **2020**, *14*, 51–58, doi:10.9790/2402-1402025158.
35. Cobzaru, C.; Olteanu, A.; Marinoiu, A.; Cernătescu, C.; Asachi, G. NATURAL AND ARTIFICIAL DEHYDRATATION OF APPLES AND BANANAS. COMPARATIVE STUDIES. **2019**, *65*, 40–49.
36. Batista, D. de V.S.; Cardoso, R.L.; de Godoy, R.C.B.; Evangelista-Barreto, N.S. Estabilidade Físico-Química e Microbiológica de Banana Passa Orgânica. Ciência Rural 2014, 44, 1886–1892, doi:10.1590/0103-8478CR20130442.
37. Isaac, A.; Davis, J.; Livingstone, C.; Wain, A.J.; Compton, R.G. Electroanalytical Methods for the Determination of Sulfite in Food and Beverages. *TrAC Trends Anal. Chem.* **2006**, *25*, 589–598, doi:10.1016/J.TRAC.2006.04.001.
38. Kaveh, M.; Abbaspour-Gilandeh, Y.; Fatemi, H.; Chen, G. Impact of Different Drying Methods on the Drying Time, Energy, and Quality of Green Peas. *J. Food Process. Preserv.* **2021**, *45*, e15503, doi:10.1111/JFPP.15503.
39. Cui, Z.W.; Xu, S.Y.; Sun, D.W. Dehydration of Garlic Slices by Combined Microwave-Vacuum and Air Drying. *https://doi.org/10.1081/DRT-120023174* **2007**, *21*, 1173–1184, doi:10.1081/DRT-120023174.
40. Takougnadi, E.; Boroze, T.E.T.; Azouma, O.Y. Effects of Drying Conditions on Energy Consumption and the Nutritional and Organoleptic Quality of Dried Bananas. *J. Food Eng.* **2020**, *268*, 109747, doi:10.1016/J.JFOODENG.2019.109747.
41. Travaglini, D. A., Neto, P. M., Bleinroth, E. W., & Leita˜ o, M.F.F. Banana-Passa Princı´pios de Secagem—Manual Te´cnico. *Campinas, SP., Bras. ITAL.* **1993**, *no.12.*
42. Wellner, A.; Huettl, C.; Henle, T. Formation of Maillard Reaction Products during Heat Treatment of Carrots. *J. Agric. Food Chem.* **2011**, *59*, 7992–7998, doi:10.1021/JF2013293.
43. Liu, X.; Xia, B.; Hu, L.T.; Ni, Z.J.; Thakur, K.; Wei, Z.J. Maillard Conjugates and Their Potential in Food and Nutritional Industries: A Review. *Food Front.* **2020**, *1*, 382–397, doi:10.1002/FFT2.43.
44. Bennett, L.E.; Jegasothy, H.; Konczak, I.; Frank, D.; Sudharmarajan, S.; Clingeleffer, P.R. Total Polyphenolics and Antioxidant Properties of Selected Dried Fruits and Relationships to Drying Conditions. *J. Funct. Foods* **2011**, *3*, 115–124, doi:10.1016/J.JFF.2011.03.005.
45. Dufera, L.T.; Hofacker, W.; Esper, A.; Hensel, O. Physicochemical Quality of Twin Layer Solar Tunnel Dried Tomato Slices. *Heliyon* **2021**, *7*, e07127, doi:10.1016/J.HELIYON.2021.E07127.
46. Kapasakalidis, P.G.; Rastall, R.A.; Gordon, M.H. Extraction of Polyphenols from Processed Black Currant (Ribes Nigrum L.) Residues. *J. Agric. Food Chem.* **2006**, *54*, 4016–4021, doi:10.1021/JF052999L.

47. Oszmiański, J.; Wojdyło, A. Effects of Blackcurrant and Apple Mash Blending on the Phenolics Contents, Antioxidant Capacity, and Colour of Juices. *Czech J. Food Sci.* **2009**, *27 (2009)*, 338–351, doi:10.17221/20/2008-CJFS.
48. Elicin, A. K., & Sacilik, K. An Experimental Study for Solar Tunnel Drying of Apple. *Tarim Bilim. Derg.* **2005**, *11*, 207-211.
49. Pekke, M.A.; Pan, Z.; Atungulu, G.G.; Smith, G.; Thompson, J.F. Drying Characteristics and Quality of Bananas under Infrared Radiation Heating. *Int. J. Agric. Biol. Eng.* **2013**, *6*, 58–70, doi:10.25165/IJABE.V6I3.739.