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Chemical and Technological Evaluation of Pepino (*Solanum muricatum*) Fruit and Their Drying Aspects

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ABSTRACT

Pepino (*Solanum muricatum*) was recently introduced to Egypt and is mostly grown in the greenhouse. So, this study aimed to evaluate the physical and chemical characteristics of fresh pepino fruits and the effect of the drying process on the quality attributes of the dried product. The osmotic dehydration method was combined with hot-air drying at 60°C. Products with varying moisture contents (25.8%, 23.23%, 20.55%, and 18.71%, labeled as T1, T2, T3, and T4, respectively) were produced to evaluate the effect of drying on the chemical, physical, microbiological, and sensory characteristics of the treatments and to identify the optimal one. The study revealed significant differences in chemical properties as moisture content decreased: hardness and color change (ΔE) values increased, while microbiological counts decreased. Statistical analysis of sensory evaluation data further indicated that treatment T3 (20.55% moisture), followed by T4 (18.71% moisture), achieved the highest general acceptance (IA) scores compared to other treatments. These findings suggest that osmotic dehydration as a partial drying pretreatment for pepino fruit slices enhances sensory properties and improves the final product quality.

1. Introduction

Pepino (*Solanum muricatum*), which belongs to the Solanaceae family, is an herbaceous perennial plant originally cultivated in the Andean region of South America and has been widely distributed throughout the world. It is commonly called pepino or melon pear and can be grown under varied soil and climatic conditions (Kumar et al., 2017). The pepino fruit has several health benefits and, in recent years, has gained global recognition for its unique flavor and aroma. The fruits have been used traditionally to treat hypertension and diabetes mellitus (Virani et al., 2020). Pepino is a lesser-known crop from the tropical and subtropical Andes, esteemed for its edible fruits, which are juicy, aromatic, mildly sweet, and fragrant, with significant variations in color, size, and shape depending on the cultivar (Kola et al., 2015). Pepino is primarily grown in China, specifically in the Haidong region of Qinghai and the Wuwei and Jiuquan regions of western Gansu. The most often used term for it is dulce, which refers to its sweeter flavor than cucumbers (Yang et al., 2021). The quality of pepino fruit is heavily influenced by environmental factors. For instance, sugar concentration is adversely affected by high temperatures during ripening. To produce high-quality fruits, it is recommended to plant pepinos during the autumn-to-winter period in Mediterranean climates. Under these conditions, the soluble solids concentration (TSS) rarely exceeds 8°Brix, a low TSS value by European consumer standards. Additionally, the fruit's color transitions from green to golden yellow, often accompanied by purple stripes, during ripening (Kola et al., 2015). Pepino comprises 92% water by fresh weight, is low in calories, and is rich in minerals such as calcium, phosphorus, and potassium. It also contains vitamins like ascorbic acid (vitamin C), thiamin (B1), riboflavin (B2), and niacin (B3), which are essential for antioxidant reactions and metabolic processes (Shathish and Guruvayoorappan, 2014).

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Analysis of volatile aromatic compounds in pepino has revealed that the fruit contains terpenes and β-damascenone, which contribute to its distinctive aromatic profile (Prohens et al., 2007). Additionally, pepino is rich in phenolic acids and flavonoids (Hsu et al., 2011). The fruit is associated with numerous health benefits, including managing diabetes, stroke, hypertension, heartburn (indigestion), cancer, kidney disorders and anti-inflammatory (Chan et al., 2024). Pepino may significantly enhance dietary antioxidant intake and is recognized for its high antioxidant capacity (Chun et al., 2005).

Drying is a critical process in the fruit processing industry, aimed at reducing moisture content to levels that inhibit deterioration reactions. Oven drying is a conventional method for fruits and vegetables (Lopez et al., 2017). However, prolonged heat exposure often induces physicochemical changes (Ciemniewska-Zytkiewicz et al., 2014). Enhanced nutrient retention and sensory quality have been reported by Krasnova et al. (2018) through the combined use of osmotic and convective drying. This pretreatment not only preserves product structure but also facilitates water removal by immersing the sample in a hypertonic sugar solution. During this process, a simultaneous counter-current mass transfer occurs: water diffuses from the cytoplasm into the solution, while solutes migrate into the sample (Yadav and Singh, 2014).

Osmotic dehydration (OD) is widely regarded as an optimal pretreatment for minimizing energy consumption, reducing thermal damage, and improving drying efficiency. The method involves immersing food material in a hypertonic solution, leading to water and small solute loss from the matrix into the solution, alongside solids absorption into the sample driven by osmotic pressure gradients. The rate of mass transfer depends on factors such as the type of osmotic agent, temperature, solute concentration, stirring speed, fruit dimensions, fruit ripeness level, and fruit-to-osmotic-agent mass ratio. Various osmotic solutes can be used in the food industry, including sucrose, glucose, fructose, maltodextrin, sorbitol, sodium chloride, and their mixtures. Osmotic dehydration (OD) has been successfully applied as a pretreatment for fruits such as lemon, kiwi, pineapple, and apricot. This process is typically conducted at mild temperatures (Ciurzyńska et al., 2016). Pretreating fruits with OD for 30 or 45 minutes before hot-air drying reduced total drying time to 7 and 8 hours, respectively (Sakooei-Vayghan et al., 2020). While OD effectively removes moisture, further air drying is required to achieve the low moisture levels necessary for safe preservation. Studies have shown that OD-pretreated foods retain superior quality (e.g., texture, color, nutrients) compared to untreated fresh samples (Nabnean et al., 2017). This study aimed to (1) evaluate the nutritional value of cultivated pepino fruit in Egypt and its derived products, (2) identify bioactive compounds in pepino fruit, and (3) analyze the physical and chemical properties of the fruit and its processed forms.

Additionally, it explored the potential of combining osmotic dehydration (OD) with hot-air drying to preserve nutritional quality, enhance product attributes, and reduce energy consumption and processing time.

2. Materials and Methods

Materials

Pepino fruits were purchased from the greenhouse at Aboshalaby Farm in Fakous City, Al-sharkya Governorate, Egypt. The fruits were harvested and stored at 5°C until analysis. Sucrose was procured from Sugar and Integrated Industries Co. (Hawamdeia, Giza, Egypt). Citric acid and potassium sorbate were obtained from El Nasr Pharmaceutical Company (Egypt). Plate Count Agar (PC A) and malt agar media were sourced from Biolife Co. (Italy). All chemicals used in this study were of analytical grade.

Methods

Technological methods

Preparation of Pepino Fruit

Pepino fruits were selected based on uniform size, color, and ripeness via visual inspection, with no signs of mechanical damage. The fruits were washed with tap water, peeled, deseeded, and sliced into 5–7mm thick sections.

Osmotic Dehydration treatments

Pepino slices were immersed in a 55°Brix sucrose solution at 45±5°C, using a fruit-to-syrup ratio of 1:2 (w/w), until the moisture content decreased to 55%. Citric acid (0.3%) and potassium sorbate (0.05%) were added to the osmotic solution. After immersion, the slices were drained, rinsed with cold water, air-dried on filter paper, and weighed.

Convection Drying by Air Oven Dryer

Partially dehydrated pepino slices (from osmotic pretreatment) were transferred to an electric air oven dryer and dried at 60 ± 5°C until reaching target moisture contents of 25%, 23.23%, 20.55%, and 18.71% (labeled T1–T4, respectively). The dried samples were packaged in low-density polyethylene (LDPE) pouches for subsequent analysis. Untreated fresh slices served as the control.

Analytical methods

Physical properties

Fruit quality attributes were assessed immediately after harvest. Five pepino fruits were cut into quarters, and each quarter was separated into core and peel tissues. Samples were homogenized using a food processor. Fresh weight, juice yield, seed mass, peel mass, flesh mass, diameter, length, and firmness were determined for five pepino fruits (Kola, 2010).

Physiochemical analyses

Moisture, total solids (TS), total soluble solids (TSS), pH value, total acidity (as citric acid), total sugars, reducing sugars, non-reducing sugars, ash, crude fiber, fat and protein were determined according to AOAC (2019). Total carbohydrates were calculated by difference as follow:

Total carbohydrates = 100 - (moisture + protein + lipids + ash + fiber)/100g.

Determination of bioactive compounds

Total phenols were determined using the Folin -Ciocalteu reagent method, Ghosh et al. (2021). Total flavonoid content was measured as described by Matic et al., (2017). Vitamin C was determined via the indophenol method (Nielsen, 2010). DPPH radical scavenging activity was assessed according to Rojas-Ocampo et al. (2021). Vitamin C served as the positive control. Percent inhibition of free radical DPPH (I %) was calculated as follows:

I % = (A control - A sample / A control) × 100

Determination of β-carotene content

The extraction of β-carotene was performed following the method described by Hagos et al. (2022) with minor modifications. Briefly, 0.5g of homogenized sample was soaked in 10mL of acetone under dark conditions at room temperature. The mixture was magnetically agitated for 30 minutes. This step was repeated until the pulp became completely colorless.

The extracts were centrifuged (4000rpm, 10min) to isolate the supernatant, and the volume was adjusted to 30 mL using fresh acetone. β-Carotene content was quantified using a UV-Vis spectrophotometer (Jenway Model 6705, UK) by measuring absorbance at 453nm, as described by Hagos et al. (2022).

Fractionation of phenolic compounds

HPLC analysis was performed using an Agilent 1260 series liquid chromatography system. Separation was achieved using an Eclipse C18 column (4.6mm × 250mm internal diameter, 5µm particle size). The mobile phase comprised (A) water and (B) 0.05% trifluoroacetic acid (TFA) in acetonitrile, delivered at a flow rate of 1mL/min. A linear gradient elution was programmed as follows: 0min (82% A); 0–5min (80% A); 5-8min (60% A); 8-12min (60% A); 12-15min (85% A) and 15-16 min (82% A). Detection was performed using a diode array detector (DAD) at 280nm. The injection volume was 10µL per sample solution, and the column temperature was maintained at 35°C. Phenolic compounds were quantified via external standard calibration at 280nm. All reported values are the mean of two independent injections (Khalil et al., 2020).

Liquid chromatographic analysis of sugars

High-performance liquid chromatography (HPLC) was used to quantify the sugar fractions (sucrose, glucose, and fructose), which were modified from Bartolome et al. (1995) and Shui and Leong (2002). Analyses were conducted on a Perkin Elmer HPLC system equipped with Total Chrom Navigator 6.2.1 software, a series-200 pump, and a refractive index (RI) detector (Perkin Elmer, Waltham, MA, USA). Separation and quantification followed the protocol by Bartolome et al. (1995), with sugars detected via the RI detector using a refractive index (RI) detector (Perkin Elmer). The separation was carried out on a SGE SS Exsil amino column (250 x 4.6 mm ID). The elution solvent used was 80% acetonitrile and 20% deionised water. The column was operated at 30°C with 0.9ml/min flow rate. Injection volume of sample was 20µl.

Color measurement

The color of fresh and dried pepino samples was determined using a Hunter Lab colorimeter. Three measurements per sample were recorded for a* (green to red), b* (blue to yellow), and L* (lightness) values, following the Hunter scale (Kumar et al., 2014).

Microbiological analysis

Microbiological analysis was carried out using the procedures established by the Bacteriological Analytical Manual (FDA, 2011).

Sensory evaluation

Color, odor, taste, texture, and overall palatability of pepino slices were evaluated by nine trained panelists from the Food Technology Research Institute, Agricultural Research Center (Giza, Egypt). A 9-point hedonic scale was used, ranging from “like extremely (9)” to “dislike extremely (1)”. The acceptance index (IA) was calculated as described by Reis et al. (2018).

Statistical analysis

Data were analyzed using SPSS 20.0 (Statistical Package for the Social Sciences). Mean values, standard deviation (SD), and least significant difference (LSD) were calculated. A one-way analysis of variance (ANOVA) was performed, and Duncan’s multiple range test was applied to compare means. Statistical significance was set at $P \leq 0.05$.

3. Result and Discussion

Table 1 shows the mean values and standard deviations of physical characteristics of pepino fruit. Pepino fruits were egg-shaped, watery in texture, 325.67g normal weight, hollow in the middle with several small seeds attached (50.67g), thin peels (25.67g), flesh (249.33g) constituted the majority of pulp parts, 9.22cm in diameter, 9.67cm in length. Also, a study cleared that pepino melons could weigh between 210 and 370 g, with a juice yield ranging between 60 to 68% (Di Scala et al., 2011). Firmness is one of the most desirable attributes in fresh produce. Pepino fruit firmness showed an accelerated loss of flesh firmness during fruit development, reaching 50.33N.

Depending on the maturation stage, the storage conditions have a strong impact on the shelf life of pepino fruit, with the loss of firmness the main limiting factor for riper stages (Contreras et al., 2016).

Table 1. Physical characteristics of pepino fruits means ± SD)

Parameters	Fresh pepino fruit
Weight (gm)	325.67± 6.03
Seeds (gm)	50.67± 1.15
Peels (gm)	25.67± 4.04
Flesh (gm)	249.33 ± 1.15
Diameter (cm)	9.22 ± 0.42
Length (mm)	9.67 ± 1.53
Length/Diameter ratio (cm)	1.05 ± 0.19
Firmness, N	50.33 ± 3.512

Also, in fresh fruit, firmness is one of the most desirable qualities. The firmness of pepino (*Solanum muricatum* Aiton) fruit ranged from 33.3 to 82.3 N and 17.6 to 78.4 N during fruit development in 2015 and 2016, respectively, according to Contreras et al. (2019). These values are comparable to the 50.33 N value found in this study. The chemical characteristics of pepino fruit are given in Table 2. In this study, pepino fruit was found to be low in sugar and calories because of its high moisture content (88.687%) (Kola, 2010). Pepino fruit had low acidity (1.35% on a dry-weight basis) and achieved a good flavor through increased total soluble solids.

Also, fructose, glucose, and sucrose were main carbohydrates in pepino, with fructose being the most abundant in green fruit. In addition, fructose and glucose decline while sucrose content increases, in fruit ripens (Contreras et al., 2019). However, total sugar content (48% on a dry-weight basis) increased during maturation and ripening. Free sugars play an important role in the flavor characteristics of pepino fruit. As indicated, sucrose contributes to sourness, sweetness and mouthfeel. Acceptance of pepino fruits by consumers was higher when they contained more sweetness and a low sugar content of pepino is beneficial for diabetic and sugar-free diets (Contreras et al., 2016). The citric acid content increased by 25% in ripe fruit compared to immature fruit (Kola et al., 2015). The chemical characteristics of the pepino fruit are given in Table 2. In this study, pepino fruit was found to be low in calories and sugar, because of its high moisture content (88.69%) (Kola, 2010). Chemical constituents of fresh pepino fruits are given in Table 2. Results declare that, pepino fruit contain low total soluble solids (TSS%) seeing 5.96% which reflect a lower content of sugars and organic acids (acidity %). Fresh pepino fruits used in this study contain (2.02%) reducing sugars; (5.43%) total sugars; and (0.15%) acidity as citric acid, on fresh basis, respectively. Our results are in accordance with the findings of (Kola 2010, 2015). Total soluble solids and sugar contents widely differ and affected by pepino fruit cultivar, maturity stage and environmental conditions. Sugars and total soluble solids accumulate and increases parall with fruit development and maturation (Kola, 2010 and Contreras et al., 2019). Also, The citric acid content increased by 25% in ripe fruit compared to immature fruit (Kola et al., 2015).

Table 2. Chemical characteristics of pepino fruits (mean ± SD)

Parameters	Fresh pepino fruit	
	FW	DW
Moisture %	88.687± 0.277	-
T.S %	11.31± 0.277	-
T.S.S%	5.96 ± 0.200	-
pH value	5.327± 0.068	5.327± 0.068
Acidity% (as citric acid)	0.153 ± 0.017	1.350 ± 0.151
Total sugar %	5.43 ± 0.164	48.00 ± 0.750
Reducing sugar %	2.02 ± 0.136	17.88 ± 0.863
Non reducing sugar %	3.41 ± 0.030	30.13 ± 0.493
Ash%	0.51 ± 0.071	4.49 ± 0.525
Crude Fiber %	0.35 ± 0.021	3.07 ± 0.115
Total Fat %	0.16 ± 0.026	1.40 ± 0.212
Total Protein %	0.51 ± 0.026	4.55 ± 0.304
Total Carbohydrate %	9.78 ± 0.239	86.50 ± 0.323
Caloric value, kcal /100 g	42.62±0.838	376.74±1.821

Additionally, the data in Table 2 show that, pepino fruit contain low amounts of ash, fibers, fat and protein being o.51, 0.35, 0.16 and 0.51% on wet basis, respectively. These results are in agreements with Yalcin, (2010). Low amounts of pepino fruit sugars, protein, fat, fiber and ash may be attributed to low total solids (dry matter) (Yue et al., 2019). Also, pepino fruit contain fiber similar to that of oatmeal, which helps to lower cholesterol, and it is easy to digest. Moreover, pepino fruit contains a low amount of calories, hence it helps in losing weight. It could be noticed that all calories in the pepino fruit come from its carbohydrate content. Pepino fruit grown in Egypt contain 48.01 and 86.50% total sugars and total carbohydrate, on dry weight basis, in succession. The carbohydrate in the pepino melon are broken down into glucose during digestion (Maheshwari et al., 2014). Generally, sugars are one of the biochemical components of fruits and the amount of sugars directly influences fruit quality. Soluble sugars are the major constituents of the fruit that play significant roles in determining fruit flavor and taste of fruit (Blando and Jomah, 2019, Minas et al., 2018).

As mentioned above in Table 3, total sugars in pepino fruit are 5.43% (wet weight basis) which mainly consists of fructose, glucose and sucrose, with fructose being the most abundant when the fruit still green. As the pepino fruit ripens, the sucrose content accumulates and increases, while fructose and glucose decreases (Contreras et al., 2019).

Table 3. Fractionation of sugars content in pepino fruit

Sugars	gm/100gm FW
Fructose	1.33
Glucose	1.32
Sucrose	2.18

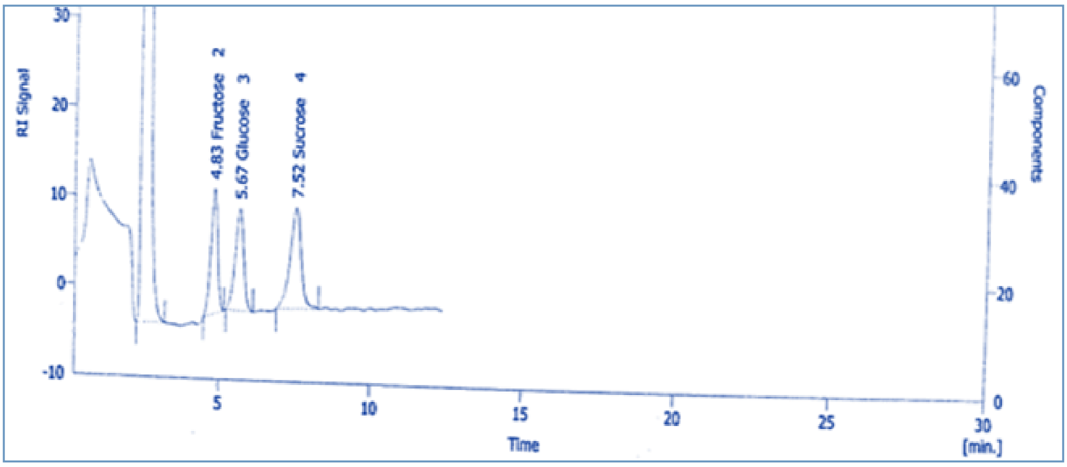

Figure 1. Sugar analysis chromatogram of pepino fruit using HPLC

Soluble sugars (fructose, glucose and sucrose) in pepino fruit were fractionated using HPLC and the data was represented in Table 3, and illustrated in fig1. The results declare that fructose, glucose and sucrose are the main soluble sugars in pepino fruit, representing 1.33, 1.31 and 2.18%, respectively. Actually sucrose has been described to account for nearly 50% of total sugars content (Contreras et al., 2019). A low sugar content of pepino is beneficial for diabetic, sugar-free diets and low-carbohydrate diets (Mahato et al., 2016)

Bioactive compound in pepino fruit

As Shown in Table 4, pepino fruit is rich in polyphenols and flavonoids (5.35mg GAE/g FW and 3.66 mg RE/g FW, respectively), which have been related with health benefits such as antioxidants through anti-inflammatory activity, scavenging reactive oxygen species (ROS) and antidiabetic effects. According to some research, ripened pepino fruit has a higher phenolic content than unripened fruit (Herraiz et al., 2016). Additionally, pepino extract contains a quantity of flavonoids in addition to phenolic acids, which inhibit oxidative stress, specifically lipid peroxidation, according to its constituents. Additionally, the flesh of pepino fruit contains other antioxidants like carotenoids (β-carotene) (10.23mg/100g FW) and vitamin C (31.69mg/100g). Because of its limited stability under heat treatments, vitamin C is regarded as a quality indicator in food processing. Pepino contains vitamin C at higher levels than those found in most fruits, including citrus fruits (Kola et al., 2015). Therefore, vitamin C has antioxidant properties, such as effectively protecting against harmful free radicals and scavenging them. (Chan et al., 2024).

Table 4. bioactive compounds of pepino fruit (on FW)

Parameters	Fresh pepino fruit
Total phenolic compounds (mg/ g FW as Gallic acid)	5.35±0.523
Total flavonoid compounds (mg/ g FW as Rutin)	3.66 ± 0.410
Total carotenoids (as β -carotene mg/100g FW)	10.23±0.191
Ascorbic acid (mg/100gm FW)	31.69±0.346
DPPH 1.0mg/ml extract %	86.82±0.433

Values are expressed as mean ± SD (n =3) β-carotene is one of the most prevalent and significant carotenoids found in most fruits, including pepino. According to reports, the amount of β-carotene in pepino increased significantly as the fruit ripened from the immature to the mature stage and stayed consistent after the fruits reached the ripe stage. which may support antioxidant activity against free-radical-mediated damage and reduce the risk of chronic diseases (Mieszczakowska-Frac et al., 2021). Although it is less tasty, pepino is rich in β-carotene and nutrients that can ward off cancer, stroke, hypertension, diabetes, as well as lower blood cholesterol levels (Maheshwari et al., 2014).

Through fractionation of phenolic compounds in pepino fruit (Table 5 and Fig. 2), it was observed that gallic acid was the most abundant phenolic compound (268.26 µg/g), followed by chlorogenic acid (59.88 µg/g). Hydroxycinnamic acid (HCA) is one of the most abundant polyphenols, exhibiting antioxidant properties via scavenging reactive oxygen species (ROS) (Herraiz et al., 2016). Cheng et al. (2019) indicated that chlorogenic acid has a comprehensive antioxidant mechanism, summarized as directly scavenging free radicals through its polyhydroxyl structure, activating antioxidant signaling pathways, regulating gene expression, enhancing antioxidant capacity, and modulating endogenous oxidase activity. Additionally, Serina and Castilho (2021) showed that polyphenolic substances could help protect nerve fibers against demyelination caused by neuroinflammation and oxidative stress. Chlorogenic acid in pepino fruit also decreased the production of NO and the expression of the pro-inflammatory cytokines COX-2 and iNOS. (Herraiz et al., 2016). Additionally, chlorogenic acid and gallic acid exhibit anti-inflammatory, antimutagenic, and antiproliferative activities (Huang et al., 2010). Gallic acid's potent antioxidant capabilities enable it to neutralize free radicals, reduce oxidative stress, and protect cells from damage. It also exerts anti-inflammatory effects by inhibiting inflammatory cytokines and enzymes, potentially aiding in managing inflammatory and cardiovascular diseases, such as lowering blood pressure and cholesterol (Hadidi et al., 2024).

Table 5. Fractionation of phenolic and flavonoid compounds in pepino fruit (on WW)

Polyphenols compound			
Phenolic acids			
Hydroxybenzoic	Conc.µg/g	Hydroxycinnamic	Conc.µg/g
Gallic acid	268.26	Chlorogenic acid	59.88
Syringic acid	2.62	Pyro catechol	7.57
Methyl gallate	1.26	Coffeic acid	5.08
Ellagic acid	1.00	Ferulic acid	4.85
-	-	Coumaric acid	1.09
-	-	Cinnamic acid	0.16
Flavonoids compounds Conc. µg/g			
Hesperetin	2.51	Kaempferol	1.16
Rosmarinic acid	2.07	Rutin	0.91
Querectin	1.68	Naringenin	0.68
Catechin	1.55	Vanillin	0.34

According to Sudha et al. (2012), flavonoids have also been found in pepino melon extract, which inhibits oxidative stress, specifically lipid peroxidation. Coumaric acid (1.09µg/g) and caffeic acid (5.08µg/g) may be responsible for the neuroprotective impact (Ma et al., 2016). By enhancing insulin sensitivity and decreasing insulin resistance, active flavonoids such as quercetin (1.68µg/g) found in pepino are associated with anti-diabetic benefits (Chan et al., 2024). Additionally, by boosting glucokinase (GLK) expression and controlling glucose metabolism, quercetin and other polyphenols may improve glucose homeostasis (Alam et al., 2022).

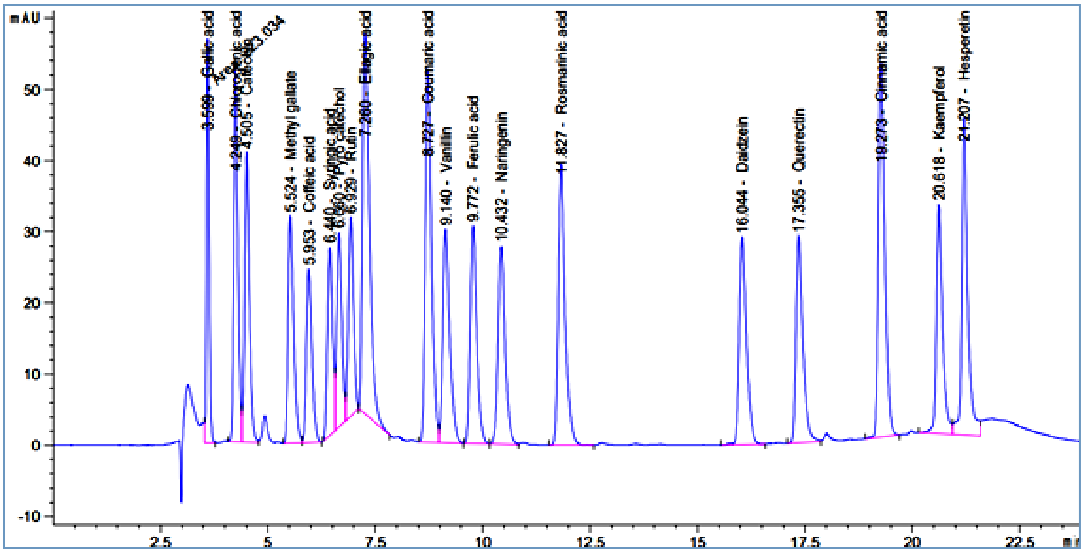

Figure 2. HPLC chromatogram of phenolic acids and flavonoids of fresh pepino fruit

The demand for higher-quality dry goods is rising, and the market for dehydrated fruits is expanding quickly. The basic factors driving food dehydration, such as diffusion and external resistance, must therefore be simulated using mathematical equations to optimize the drying process (Giner, 2009). The main goal of drying agricultural products is to remove water from the solids to a point where chemical reactions and microbiological spoilage are significantly reduced, extending shelf life. Hot air drying is the foundation of most industrial drying processes, and osmotic dehydration is one of the most crucial complementary treatments and food preservation techniques, offering advantages such as reducing heat damage to flavor and color, preventing enzyme browning, lowering energy costs, and adding value to the final product, which is nutritious and available year-round. The most effective method to reduce energy usage, boost throughput, and enhance product quality is to combine osmotic dehydration with convective, freeze-drying, microwave, vacuum, or infrared drying (Ramya and Jain, 2017). The drying curve in Fig. 3 demonstrates that moisture content decreases as drying time increases for both air oven-dried samples and those dried by combined osmosis and air oven drying. Additionally, the drying rate of the OD sample was higher compared to the OOD sample.

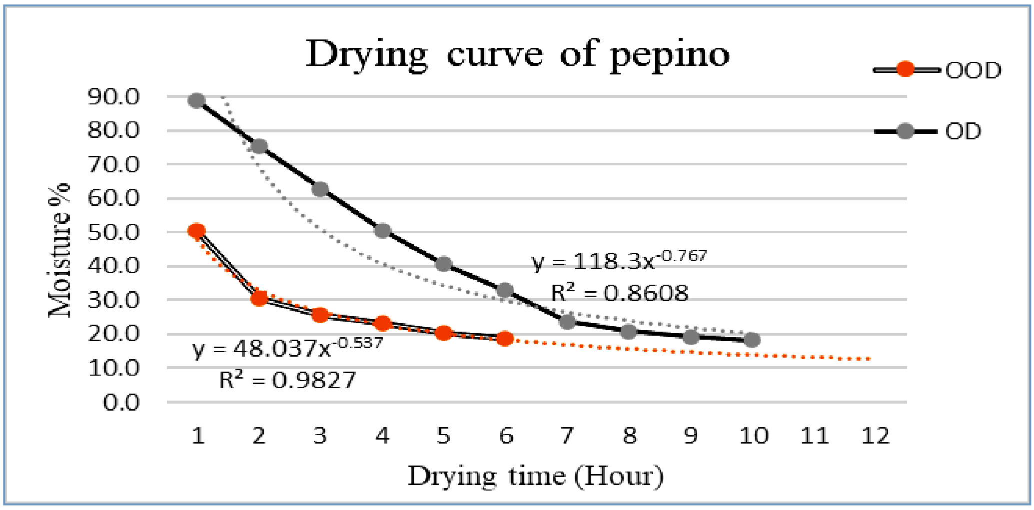

Figure 3. Drying curve of Pepino fruit slices by air oven drying (OD) and combined drying (OOD)

As a result, the drying process is divided into three phases: preheating, constant rate, and falling rate. During the preheating phase, heat is utilized only until the sample reaches the drying temperature and the drying rate approaches zero. Subsequently, mechanically bound water on the sample surface is steadily evaporated. During the falling rate phase, physicochemically bound water leaks out as the drying rate decreases. The drying rate slows due to reduced moisture content. The decreasing rate period in pepino slices indicates that internal moisture diffusion controls the drying process. Osmotic dehydration (OD), a mild, non-thermal process involving immersion in a hypertonic solution, is typically used as a pretreatment for preservation techniques like drying or freezing (Dermesonlouoglou et al., 2020). Osmotic dehydration with sucrose solution enhanced moisture reduction and lowered the drying ratio of pepino slices (OOD) compared to other dried samples (OD). Our findings align with Badee et al. (2019) who reported that osmosis dehydration of apricot halves as a pretreatment with sucrose solutions helps to lower the drying ratio, which in turn increases the solids' transfer process, saving time and power. Effect of drying process on physio-chemical characteristics of dried pepino fruit. The chemical characteristics of fresh and dried pepino fruit are shown in Table 6. Significant differences were observed between dried samples, reflecting the drying process's effects. Moisture content decreased, but total solids were increased after the drying process. Acidity decreased due to organic acid migration into the hypertonic solution during osmotic dehydration and convective drying (Juhnevica-Radenkova et al., 2024). Table 6 shows reductions in crude fiber, total fat, and total protein also decreased. The loss of crude fiber may result from thermal degradation disrupting the polysaccharide network in cell walls (Miranda et al., 2010). Reducing total protein after drying, likely due to Maillard browning during high-temperature processing. The Maillard reaction occurs naturally during thermal processing and storage through interactions between reducing sugars and amino acids (Kolla et al., 2021). Additionally, drying reduces nutritional components, including flavonoid and phenolic compounds, and lowers antioxidant activity, which lowers the nutritional benefits of dried fruits. Furthermore, the fruit type, drying technique, and processing factors all affect the particular chemical and physical changes that occur in the dried fruits (Ismail and Gögüs, 2023).

Table 6. Effect of drying on physio-chemical characteristics of dried pepino fruit (Means± SD)

Characteristics	Dried treatments			
	T1	T2	T3	T4
Moisture, %	25.80[a]±0.131	23.23[b]±0.150	20.55[c]±0.210	18.71[d]±0.145
pH	4.35[c]±0.037	4.42[bc]±0.030	4.48[ab]±0.055	4.52[a]±0.025
Total acidity, %	0.693[a]±0.020	0.622[b]±0.014	0.545[c]±0.025	0.493[d]±0.025
Ash, %	2.10[d]±0.069	2.32[c]±0.056	2.65[b]±0.107	2.88[a]±0.067
Crude fiber, %	1.83[a]±0.069	1.61[b]±0.038	1.44[bc]±0.166	1.34[c]±0.081
Lipids, %	0.907[a]±0.040	0.847[a]±0.034	0.719[b]±0.024	0.594[c]±0.048
Protein, %	2.66[a]±0.262	2.36[a]±0.156	1.99[b]±0.133	1.80[b]±0.058
Total carbohydrates, %	66.70[d]±0.125	69.63[c]±0.117	72.65[b]±0.141	74.67[d]±0.274
Caloric value, kcal /100 g	310.8[a]±1.002	305.0[b]±0.838	295.6[c]±1.158	286.0[d]±1.117
Firmness, N	29.91[d]±0.580	32.44[c]±0.461	34.44[b]±0.541	37.06[a]±0.338

Means within a raw showing the same letters are not significantly different (P≤ 0.05)

Our findings in Table 6 indicate significant texture changes due to osmotic dehydration, with dried pepino showing firmness below 50.30N compared to fresh pepino. Moisture reduction in dried samples (from 25.80% to 18.71%) resulted in increased hardness (29.91N to 37.06N). These results align with Yazidi et al. (2024), who reported that osmotic -treated orange slices (in sucrose) had reduced hardness due to pectin structural changes, leading to a softer texture. Firmness is a critical structural attribute of dried foods; osmotic drying typically softens fruits due to tissue alterations, making them more susceptible to mechanical stress, influenced by solution concentration and solute type (Mokhtar and Thow, 2022).

Effect of drying process on bioactive compounds of dried pepino fruit

Bioactive compounds - biologically active secondary metabolites - are found in various foods, primarily plant-based sources. Antioxidants like total phenolics, flavonoids, and carotenoids were significantly higher in dried fruits than fresh (Table 7), likely due to compound concentration during drying (Nunes et al., 2016). Heating disrupts pepino's cell structure, releasing phenolics into extraction solutions and enhancing phenolic/antioxidant activity (Szychowski et al., 2018). Thus, the higher phenolic content in dried pepino suggests potential health benefits, such as neutralizing free radicals. Table 7 findings suggest that samples with lower moisture content had reduced bioactive substances as drying time increased, with greater variation in compound content at longer drying times. Moderate heat during drying cleaves phenolic glycosidic bonds, forming phenolic aglycons that react more effectively with the Folin–Ciocalteu reagent, increasing total phenolic values. Heat also degrades pigments like carotenoids (Table 7), responsible for the fruit's yellow color.

Table 7. Bioactive compounds (mean±SD) of fresh and dried pepino fruit

Parameters	Fresh pepino		Dried Treatments T1		T2		T3		T4	
	FW	DW	FW	DW	FW	DW	FW	DW	FW	DW
Total phenolic compounds (mg/ g as Gallic acid)	5.35[e]± 0.523	47.29	22.28[a] ±0.509	30.03	19.77[b] ±0.134	25.75	16.54[c] ±0.445	20.82	14.99[d] ±0.495	18.44
Total flavonoid compounds (mg/ g as Rutin)	3.66[e]± 0.410	32.4	13.28[a] ±0.255	17.9	11.50[b] ±0.516	15.0	10.78[c] ±0.431	13.6	9.40[d] ±0.530	11.6
Total carotenoids (as β -carotene g/100g)	10.23[e] ±0.191	90.4	50.22[a] ±0.226	67.7	44.53[b] ±0.304	58.0	39.29[c] ±0.297	49.5	35.31[d] ±0.346	43.4
Ascorbic acid (Vit C) (mg/100gm)	31.69[e] ±0.346	280.1	141.68[a] ±0.573	190.9	132.54[b] ±0.481	172.6	118.54[c] ±0.177	149.2	107.47[d] ±0.368	132.2
Antioxidant activity % (DPPH)	86.82[a] ±0.433	-	78.28[b] ±0.346	-	72.28[c] ±0.392	-	69.73[d] ±0.559	-	62.23[e] ±0.458	-

Means within a raw showing the same letters are not significantly different (P≤ 0.05)

On the other hand, as fruits lose moisture, the concentration of pigments in their tissues increases, leading to a deepened color (İncedayı et al., 2016). In Table 7, ascorbic acid decreased slightly after the osmotic drying process. Sakooei-Vayghan et al. (2020) observed that osmotic drying combined with indirect heat transfer (via water bath) and coating fruits with ascorbic/citric acids preserved vitamin C. Thus, osmotic pretreatment may retain heat-sensitive ascorbic acid, but inadequate coating due to low osmotic solution concentration can lead to greater vitamin loss (Hassan et al., 2024). Phenolic compounds are critical due to their hydroxyl groups, which confer free radical scavenging ability. Both phenolics and flavonoids exhibit strong antioxidant potential, impacting human health. Flavonoids act via free radical scavenging or metal chelation. Fresh pepino showed 86.82% DPPH antioxidant activity, but activity decreased with declining moisture content, likely due to oxidative degradation of bioactive compounds during prolonged drying (Akdaş and Başlar, 2014). Degradation of phenolics, flavonoids, and carotenoids reduced antioxidant activity over different drying durations. Maillard reaction products in dried agricultural goods often show high antioxidant activity via chain-breaking mechanisms (Osae et al., 2019).

Table 8. Effect of drying process on color in pepino fruit

Parameters	Fresh	Dried Treatments			
		T1	T2	T3	T4
L^*	64.97^a±0.452	31.06^b±0.630	30.92^b±0.245	29.72^b±0.405	26.89^c±0.410
a^*	2.24^d±0.85	4.08^c±0.475	4.13^c±0.195	5.45^b±0.295	7.11^a±0.260
b^*	13.40^d±0.175	16.41^c±0.258	18.32^b±0.263	17.93^b±0.525	20.17^a±0.220
ΔE	0.00^c±0.000	22.05^b±0.930	21.78^b±0.310	22.75^b±0.530	25.07^a±0.635

Means within a raw showing the same letters are not significantly different (P≤ 0.05), Values are expressed as mean ± SD. lightness (L*), green to red (a*), blue to yellow (b*) and total color difference (Δ*E*)

The acceptance of a food product by consumers is significantly influenced by its physical attributes, with color being one of the most crucial factors. Thus, preserving product integrity throughout predrying treatments is of utmost importance. The color values (lightness, redness, and yellowness) of fresh and dried pepino slices are given in Table 8. It is well recognized that drying results in unfavorable alterations to the dried product's color, which can significantly affect its acceptance by consumers. The results in the same table demonstrate color changes estimated by L, a, and b*** during thermal processing in pepino fruit. The color coordinates L, a, and b*** show significant differences between fresh and dried samples ($p < 0.05$). The brightness (L*) decreased in all dehydrated samples compared to fresh pepino fruit. (31.06 to 26.89) compared to fresh pepino fruit (64.97). while non-significant differences were observed between T1, T2, and T3 of L*. In contrast, T4 became more dark than all samples. The lower L values* were due to the browning reaction. Meanwhile, the darkening of the fruits was due to prolonged drying time, as confirmed by Parveez Zia and Alibas (2021). The decline in lightness has been linked to water evaporation loss, surface deformation (shrinkage), and brown pigment production. These pigments develop through processes like enzymatic browning (involving phenolic compounds and polyphenol oxidases and non-enzymatic browning (Maillard reaction and auto-oxidation) (Marquez et al., 2013). This finding connects to the protective impact of osmotic pretreatment against enzymatic/oxidative browning, leading to better color with reduced lightness in dried pepino slices (Hassan et al., 2024). However, the *a value** increased in all dehydrated samples compared to fresh fruit. The increase in *a value** denotes a shift toward red chroma, indicative of browning (Deng et al., 2017). They also found that increasing drying temperature intensified pigment degradation (e.g., carotenoids) and a (greenness–redness)* values. Furthermore, drying heat degrades pigments like carotenoids, responsible for yellow fruit tissues. Conversely, moisture loss concentrates pigments, deepening color (İncedayı et al., 2016). The increase in a value* typically reflects browning (phenomenon) (García-Martínez et al., 2013). On the other hand, the yellowness (b*) value indicated that there was no significant difference for both T2 and T4. While T4 displayed higher values of yellowness (20.17). Meanwhile, fresh fruit had 13.40, the lowest value (b*). Furthermore, the heat of drying leads to the degradation or alteration of pigments that exist in the fruits, such as the carotenoids, which are responsible for the yellow color of the fruit tissues. On the other hand, as the fruits lose moisture, the concentration of pigments present in the fruit tissues becomes more concentrated, leading to a deepening of color (İnceday et al., 2016).As regards a total color difference (ΔE), it increased significantly after the drying process (Table 8). In addition to some non-enzymatic causes of browning in fruit during drying, furthermore the Maillard reaction and autoxidation reactions involving phenolic compounds (Lopez et al., 2017). Enzymatic browning occurs in fruits containing polyphenols and polyphenol oxidase, which trigger browning in oxygen. Enzymatic browning occurs in fruits containing polyphenols and polyphenol oxidase, which trigger browning in oxygen. This reaction causes discoloration, while non-enzymatic browning (e.g., Maillard reaction and caramelization) also contributes to browning in dried fruits (Deng et al., 2017). In the same trend of *L*, a*, and b** values, T4 had the highest value of (ΔE) than other traits, while there were no significant differences between T1, T2, and T3.

Table 9. Total count and yeast and mould (Log CFU/g) of fresh and dehydrated pepino slices

Properties	Treatments				
	Fresh	T1	T2	T3	T4
Total Vaible Bacteria	2.668^{a}	2.543^{b}	2.458^{c}	2.401^{cd}	2.342^{d}
Yeast and Mold	1.945^{a}	1.842^{b}	1.787^{b}	1.626^{c}	1.370^{d}
E- coli	Nil	Nil	Nil	Nil	Nil

Means within a raw showing the same letters are not significantly different (P≤ 0.05)

The changes in microbial quality of dehydrated pepino slices are presented in Table 9. The interaction of treatments and combination of osmotic and air drying played a significant role in the observed decline in total viable bacteria (TVB) and yeast and mould (Y&M). The results indicated that microbial quality improved in all treatments due to osmotic pretreatment, which enhanced microbiological properties. Moisture and food are key factors for yeast and mold growth (Gani et al., 2018). Total viable bacteria (TVB) and Y&M were lowest in the T4 sample (2.342 and 1.370logCFU/g, respectively) due to lower moisture content compared to other samples. Thus, significant differences existed between fresh and dehydrated pepino slices in TVB and Y&M, but no differences were observed between T1 and T2 in Y&M growth (1.842 and 1.787 log CFU/g, respectively). Yeast, mold, and TVB were below detection limits. This decline may result from increased drying temperature and reduced moisture content during dehydration (Dereje and Abera, 2020). Additionally, osmotic dehydration lowered water activity with increasing time and temperature (Assis et al., 2017). At low water activity, chemical reactions are reduced, and the growth of toxin-producing microorganisms is inhibited (Gani et al., 2018). Sensory evaluation serves as a crucial tool in understanding consumers' potential choices and preferences. Thus, it is imperative that such assessments accurately capture product quality, considering factors such as color, odor, taste, texture, and overall palatability of dehydrated pepino slices (Table 10). The sensory characteristics of pepino fruit are influenced by phenolic acids, saccharides, and alcohols, affecting sweetness, acidity, flavor intensity, and liking. Studies show that caffeic acid, sucrose, and glycolic acid influence four sensory attributes evaluated by consumers (Sun et al., 2022).

Table 10. Sensory evaluation of fresh and dehydrated pepino slices

Treatments	Characteristics					
	Color	Odor	Taste	Texture	Overall palatability	IA
Fresh	6.51^{c}±0.516	5.85^{c}±0.409	5.72^{c}±0.489	6.12^{d}±0.311	6.04^{c}±0.318	67.08^{c}±3.529
T1	6.60^{c}±0.459	6.83^{b}±0.586	8.04^{a}±0.507	6.65^{c}±0.668	7.01^{b}±0.360	77.92^{b}±4.00
T2	7.55^{ab}±0.485	7.65^{a}±0.529	7.05^{b}±0.41516	7.05^{bc}±0.598	7.33^{ab}±0.396	81.39^{ab}±4.401
T3	7.92^{a}±0.442	7.75^{a}±0.520	7.35^{ab}±0.668	7.75^{a}±0.424	7.69^{a}±0.468	85.42^{a}±5.207
T4	6.93^{bc}±0.378	7.95^{a}±0.468	7.95^{a}±0.565	7.40^{a}±0.559	7.55^{a}±0.457	83.89^{a}±5.079

Means within a column showing the same letters are not significantly different (P≤ 0.05)

Pepino has a subtle, mellow flavor with mild sweetness reminiscent of melon and cucumber (notably, *pepino* means *cucumber* in Spanish) (Maheshwari et al., 2014). Consequently, fresh pepino fruit received lower scores in all sensory attributes compared to dehydrated slices (Table 10). The effect of osmotic drying on sensory characteristics of the final product was evaluated in Table 10. Osmotic drying improves product quality (color, structure, texture, and sensory attributes). Mass transfer occurs through water removal and solute uptake into pepino tissue (Ciurzyńska et al., 2016). Soluble sugar content is the key indicator of fruit quality and taste (Minas et al., 2018), which improves with drying processes, aligning the fruit's chemistry with consumer preferences. In **Table 10**, the T3 sample scored highest in color, odor, texture, and overall palatability, indicating the highest consumer acceptance, followed by T4.

4. Conclusion

This study highlights the nutritional value, physicochemical properties, and bioactive compounds present in pepino fruit cultivated in Egypt. The results demonstrate that osmotic dehydration combined with hot-air drying effectively enhances the sensory and microbiological quality of dried pepino slices. Among the tested treatments, T3 (20.55% moisture) exhibited the most favorable balance between texture, flavor, and overall consumer acceptability. The drying process significantly reduced microbial loads, improved shelf stability, and preserved essential bioactive compounds. Given the health benefits and market potential of pepino fruit, further research should focus on optimizing drying conditions and exploring innovative preservation techniques to maximize product quality and consumer appeal. Expanding pepino cultivation and processing in Egypt could offer promising opportunities for both local consumption and export markets.

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