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Drying apples using a solar dryer with a desiccant cycle in two modes: direct radiation-convection and indirect radiation-convection

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ABSTRACT

The aim of the current research is to dry apples using a solar dryer with a desiccant cycle in two modes: direct radiation-convection and indirect radiation-convection. Two types of drying methods, direct and indirect with desiccant and without desiccant, moisture content, and drying in open air were used. Pre-prepared apple slices (flavored with cinnamon) were placed on a specific-sized mesh, the initial weight of the samples was measured, and they were placed inside the solar dryer with a desiccant cycle in two modes: direct radiation-convection and indirect radiation-convection. During the drying process, the evaporation rate, texture, wrinkling, water reabsorption, vitamin C retention, color changes, and sensory characteristics at different treatment levels (30% sucrose and without sucrose, 0.5%, 1%, and 2% cinnamon) were examined. Additionally, several samples were dried as controls without cinnamon flavoring using the solar dryer. Data analysis was conducted using a completely randomized factorial design and the statistical software SPSS version 26. The results of the study showed that in both direct and indirect methods, with and without desiccant, the moisture removal rate in samples without sucrose was higher compared to samples with sucrose and cinnamon. Comparing control samples in both methods with and without desiccant moisture showed that the evaporation rate of samples with desiccant moisture was significantly higher. Furthermore, in samples with sucrose, the evaporation rate was lower in the desiccant method, and in direct sunlight drying, the drying rate was significantly lower compared to solar dryer drying. The results of evaporation rates in the indirect drying method also indicated that similar to the direct method, the evaporation rate of samples with cinnamon treatment and without sucrose was higher than that of samples with sucrose and controls. Tissue analysis results also indicated that the highest firmness was observed in the direct method without desiccant for samples without sucrose, with no significant difference in means. Cinnamon also increased the firmness in samples without desiccant moisture in the indirect drying method, and samples with sucrose had less wrinkling, with an increase in cinnamon concentration leading to more wrinkling, with the highest increase observed in the direct method without desiccant at 2% cinnamon and in the direct method with desiccant at 1% cinnamon concentration. The water reabsorption rate in both direct and indirect drying methods showed that samples with sucrose had better water reabsorption conditions, and the vitamin C degradation rate indicated that the use of sucrose improved vitamin C retention. Color change analysis also showed that samples with sucrose had more favorable conditions in both methods. Therefore, the results related to sensory evaluation characteristics indicated that samples with sucrose and different cinnamon concentrations received the highest sensory evaluation scores. Hence, it can be stated that samples dried with osmotic solution and sucrose generally had better acceptability in terms of physical appearance, color, taste, and flavor.

1- Introduction

According to preliminary research findings, the world's countries currently produce an average of 89,565,973 tons of apples annually [1]. Apples are one of the most important fruits in our daily diet due to their abundant therapeutic properties and rich vitamin and trace element content. Apples are a good source of nutrients including fiber, vitamin C, and antioxidants, which can aid healthy digestion, reduce cholesterol by 10-15%, support brain health, and help manage weight, as well as protect the body against certain diseases such as cancer, heart disease, and type 2 diabetes [2, 3]. Additionally, they contain volatile fatty acids including acetic, propionic, isobutyric, and valeric acids [4]. All types of apples have only minor differences in chemical composition, and the fruit grown in different provinces and geographical latitudes also varies [5]. Nowadays, drying fruit slices such as apples, oranges, kiwis, bananas, and others has become commonplace, and the dried products are sold at very high prices in the market. Drying is one of the oldest methods of food preservation, and this process is carried out to reduce the weight of products for easier transportation, reduce packaging costs, create new shapes and flavors, and increase shelf life with minimal quality degradation during storage. Given the growing population and the fundamental need to ensure food supply, the need to preserve and maintain food resources has become particularly important, and the question arises as to whether all food items have the ability to be stored long-term or not. Since some agricultural products are seasonal, and need to be stored for other seasons, the preservation of agricultural products has long been a challenging issue for farmers. The drying method affects the quality of the dried product, and on the other hand, drying products, especially fruits, can cause damage and reduce their quality. This is because fruits, vegetables, legumes, etc., with their high moisture content and delicate texture, are sensitive to the drying process, and drying them at high temperatures in industrial dryers can cause them to lose color and flavor, while traditional drying methods can also lead to contamination and product loss [7].

According to the available statistics and studies, on average, currently 35% of agricultural products in Iran are lost annually, and this figure can reach up to 50% in some cases, especially for fruits during the summer season. As a result, the hard-earned efforts of orchard owners and other investors in this sector are wasted [8]. Therefore, drying methods have expanded, and the use of industrial dryers such as hot air, microwave, infrared, heat pump, and freeze drying has become prevalent in drying agricultural products. These dryers have advantages (compared to traditional methods) including reduced drying time and improved product quality. Since industrial drying is an energy-intensive process, selecting the appropriate drying method can not only result in economic savings and reduced energy consumption, but also improve the quality of the produced product.

Cinnamon is an evergreen spice obtained from the inner bark of several tree species of the genus Cinnamomum, and is primarily used as a fragrant seasoning and flavor enhancer [9]. The aroma and taste of cinnamon derive from its essential oil and the main component cinnamaldehyde, as well as other compounds like eugenol [10]. This plant has anti-inflammatory, antimicrobial, antioxidant, anti-tumor, cardioprotective, cholesterol-lowering, blood sugar-reducing, and immune-modulating properties [11]. According to statistics, the global production of cinnamon in 2021 was 226,753 tons, with China leading production at 43% of the world total [12].

Flavor enhancers in food products involve the use of additives to increase taste and aroma [13]. Different flavor compounds interact with each other and are affected by various factors that influence the perception of flavor [14]. Preconcentration techniques such as solid-phase microextraction (SPME) and pressurized hot water extraction (PHW) are commonly used to analyze flavor compounds in various food products [15], and researchers have found that the composition and amount of aroma compounds also play an important role in consumer acceptance of food products [15, 16]. Additionally, there are inventions related to food flavorings with non-natural ingredients, where freshly ground flavorings are applied as an instant seasoning to food [15], with the aim of improving taste and sensory experience.

It is clear that various drying methods can significantly affect food materials, leading to physical changes such as color, texture, and flavor. They can also cause unintended reactions, including the degradation of effective compounds in aromatics and nutrients [17]. Therefore, having a suitable drying method is crucial for preserving valuable food materials. Research has shown that drying can alter the properties of food materials, including discoloration, loss of aroma, changes in texture, nutritional value, and changes in physical appearance and shape [18]. Higher temperatures during drying can reduce drying time, but may lead to low-quality products, thermal damage to the surface, and increased energy consumption. On the other hand, low-temperature drying conditions may improve product quality, but reduce drying speed, resulting in a longer drying period [19].

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The study and investigation of various traditional and modern food drying methods is crucial, and this study aims to highlight the importance of using solar dryers for food drying. Dried apples have diverse quality characteristics that are influenced by the different drying methods and conditions. Lingaiah et al. (2021) found that the most important parameters affecting drying rate are temperature, air velocity, followed by solar radiation, product type, initial moisture content, and total product mass [20]. Additionally, Prohit et al. (2021) compared and financially evaluated solar drying and sun drying of food products, and their results showed that solar drying is more cost-effective due to reduced drying time and energy savings, as well as better final product quality, compared to sun drying [21].

The product developed in this research can be introduced as a new item to the market and used as a healthy snack, as it not only has the benefits of dried fruit, but also contains the properties of the added cinnamon, making it suitable for consumption by diabetic individuals. The research results can also improve the organoleptic properties, increase the shelf life, and enhance the nutritional value of the dried apples. Given that no previous research has been conducted on flavoring apple slices with cinnamon using a solar dryer, this study aims to investigate the production of cinnamon-flavored apple slices dried using a solar dryer, and to evaluate the physical properties, such as texture, moisture content, rehydration, and shrinkage, as well as the chemical and quality properties, including vitamin C changes, color, and sensory evaluation, of the dried samples.

2-Materials and methods

For this research, Lebanese yellow apple variety and cinnamon were used, and until the start of the experiment, they were stored at 4°C with 40% humidity. The initial moisture content of the apple samples was calculated to be 87.32 ± 1.65% (wet basis) using the oven drying method at 103°C for 24 hours . The chemical materials used in this study include ethanol, citric acid, 2,6-dichlorophenolindophenol (DCPIP), phosphoric acid, citrate buffer, ascorbic acid, methanol, and hydrochloric acid (HCl). All the equipment and instruments used in this research were made in Germany. The study aims to produce cinnamon-flavored apple slices dried using a solar dryer, and to evaluate the physical properties such as texture, moisture content, rehydration, and shrinkage, as well as the chemical and quality properties including vitamin C changes, color, and sensory evaluation of the dried samples

2-1- Apple sample preparation

After washing the required samples for each experiment, the surface moisture was removed using an absorbent paper, and the samples were then sliced to a thickness of 3 millimeters.

2-2- enzyme removal

After slicing the apple samples, they were immersed in a 1% citric acid solution for 5 minutes to prevent enzymatic browning . This is a common pre-treatment step in fruit drying to inhibit the activity of polyphenol oxidase enzymes that can cause undesirable discoloration of the fruit during the drying process. The citric acid solution helps preserve the natural color and appearance of the apple slices prior to the drying step [22].

2-3- Preparation of cinnamon extract

To prepare the cinnamon extract, 50 grams of cinnamon sticks were ground using a mill, and then sieved to obtain particles in the size range of 1 to 3 millimeters. An alcoholic solution (75% ethanol and 25% water) was combined with the cinnamon powder in a ratio of 6 parts solvent to 1 part powder, and the mixture was placed in a water bath at 40°C for 3 hours to allow extraction. The extract solution was then filtered using Whatman filter paper 1, and a rotary evaporator under vacuum was used to evaporate the solvent. The extract was sterilized using a 0.22 µm syringe filter, and the sterile extract was stored in a refrigerator at 4°C until further use.

2-4- Osmotic water extraction and adding cinnamon extract

A 30% sucrose solution, cinnamon extract, and a mixture of sucrose and cinnamon extract at concentrations of 0%, 0.5%, 1%, and 2% were prepared. Initially, the sucrose solution was placed in a hot water bath to reach a temperature of 40°C. The samples were then placed in the solution at different concentrations. After 120 minutes, the samples were removed from the solution and rinsed with distilled water. Throughout the process, the temperature of the solution was monitored using a thermometer to ensure it remained constant until the end of the process.

2-5- Drying with open air

The water-saturated apple samples were exposed to air and direct sunlight, and their weight changes were recorded at different time intervals [23].

2-6- Drying with a solar dryer

The solar dryer with an adsorption wheel shown in Figure 1 has two drying chambers. The first chamber (chamber 1) with dimensions of 65 × 135 cm was used for the direct solar drying process, where the drying occurs due to a combination of direct solar radiation and hot air. The second chamber was used for the indirect solar drying experiments. In this case, after the solar energy is absorbed by the first

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chamber and the inlet air temperature is increased by a fan, the hot air enters this second chamber and causes the product to dry. The second chamber has three mesh trays, and the total mass placed on these trays is equal to the capacity of the first chamber.

As shown in Figure 1, a recirculation path is used to control the return air to the dryer. The adsorption wheel mechanism is installed at the end of the return air inlet duct. Before each experiment with the adsorption wheel, the adsorbent material was loaded into the mechanism.

The solar dryer was evaluated in four different modes: 1) direct solar drying with a return air cycle without an adsorbent, 2) direct solar drying with a return air cycle and a moisture adsorbent, 3) indirect solar drying with a return air cycle (second chamber), and 4) indirect solar drying with a return air cycle and a moisture adsorbent.

To evaluate the dryer's performance in terms of energy savings, the above modes were assessed under the same temperature conditions with the hot air circulation structure (in two cases: return air cycle only and the combination of return air cycle and moisture adsorbent) [24].

Prepared apple slices (flavored with cinnamon) were placed on a specified mesh with dimensions, and their initial weight was measured. The samples were then placed in a solar dryer with an adsorption wheel in two modes: direct solar radiation with adsorption and indirect solar radiation with adsorption. During the drying process, the decrease in moisture content and temperature were monitored. Additionally, a few samples were used as controls, dried without cinnamon flavoring, solely using the solar dryer.

FIG 1: Solar dryer used in experiments

2-7- Tests

Moisture content measurement:

50 grams of the samples were weighed and then dried in an oven at 103 ± 2°C until reaching a constant weight. The moisture content was calculated using the following equation:

Moisture content (wet basis) = (M1 - M2) / M0 × 100

Where:

M1 = weight of the container and sample before drying

M2 = weight of the container and sample after drying

M0 = weight of the sample

Tissue analysis:

Texture is one of the important quality characteristics that plays a significant role in the overall acceptance of food products. The texture of the dried apple samples was evaluated using a penetration test with a texture analyzer (TA-XT Plus, Stable Micro Systems Ltd., Surrey, UK). The tests were conducted at room temperature (25°C). The entire process was controlled by the relevant software (Texture Expert 1.05), and the data was recorded using Excel software. This instrument automatically records the force-time curve. Additionally, the firmness of each sample was measured in triplicate and expressed in Newtons [25].

Rehydration:

To evaluate the rehydration capacity of the dried apple samples, the dried apple samples were first weighed and then immersed in water at 50°C. The weight ratio of apple to water was set at 1:25. After 30 minutes, the samples were removed from the water and weighed using a digital scale (AND model, Japan) with an accuracy of 0.01 g. All treatments were performed in triplicate, and the averages were reported. The rehydration ratio was then calculated using Equation 2 [26]:

$$RR=\frac{M- M0}{M0}\times 100$$

In this equation, M is the weight of the sample after rehydration and M0 is the weight of the dry sample.

Determination of shrinkage:

Image processing was used to calculate the shrinkage. Using an image processing system,

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images of the sliced apple samples were captured before and after the drying process. After analyzing the captured images using MATLAB software, the surface area of the apple samples was measured. The percentage of shrinkage was then calculated using Equation 3:

$$Sh = \frac{A_f - A_d}{A_f} \times 100$$

The variable Sh represents the percentage shrinkage of the samples, while Af and Ad are the surface areas of the fresh and dried apple slices, respectively, measured in cm².

Measurement of ascorbic acid:

To determine the vitamin C content, 0.1 g of the dried sample was mixed with 2 mL of a 5% (w/v) metaphosphoric acid stabilizing solution. The resulting solution was centrifuged at 12,000 rpm for 15 minutes at 4°C. Then, 400 µL of the supernatant or ascorbic acid standard was mixed with 200 µL of 10% (w/v) metaphosphoric acid, 600 µL of a freshly prepared citrate buffer at pH 4.2 (18.5 mL of 0.1 M sodium citrate + 31.5 mL of 0.1 M citric acid + 50 mL of distilled water), and 600 µL of 0.03% (w/v) 2,6-dichlorophenolindophenol reagent, and vortexed. The absorbance of the samples was measured at 510 nm using a spectrophotometer (Spectrophotometer unico, UV-2100, USA) after 30 minutes of incubation in the dark [23].

Measurement of color parameters:

To measure the color changes of the dried samples, the color parameters (L*-a*-b*) of the fresh and dried samples were measured using a TES 135 color meter made in Taiwan. The overall color change of the samples was calculated using Equation 4 [24]:

$$\Delta E = \sqrt{(L_f - L_d)^2 + (b_f - b_d)^2 + (a_f - a_d)^2}$$

Where ΔE represents the total color change of the sample (dimensionless), and the subscripts f and d indicate the color parameters of the fresh and dried samples, respectively.

Evaluation of sensory properties:

The samples were evaluated by a panel of 10 members, who assessed the color, aroma, taste, texture, and overall acceptance based on a 5-point hedonic scale. The ratings were divided into five classes, ranging from 1 (very poor) to 5 (very good).

3-Results and Discussion

3-1- Evaporation rate analysis

The drying rate of the apple samples under different drying conditions is shown in Figure 2. The results indicate that in the direct drying method without a moisture adsorbent, the moisture removal rate was higher for the samples without sucrose. For example, the drying rate of the sample with 0% sucrose and 1% cinnamon was 366.79 g water/h, while the sample with 30% sucrose and 1% cinnamon had a drying rate of 250.22 g water/h, which are significantly different. Furthermore, the control sample in the direct drying method without an adsorbent had a lower moisture removal rate of 205.50 g water/h compared to the other treatments. However, a comparison of the control samples between the direct drying with an adsorbent and the direct drying without an adsorbent show that the drying rate was significantly higher in the presence of the adsorbent. Additionally, when comparing the samples with sucrose between the direct drying with an adsorbent and the direct drying without an adsorbent, the results indicate that the samples with sucrose had a lower drying rate in the method with the moisture adsorbent .In the indirect drying method, the results showed that the highest and lowest drying rates in the indirect solar dryer without a moisture adsorbent were observed in the sample without sucrose and with 0.5% cinnamon, and the sample with 30% sucrose and without cinnamon, respectively. In the indirect solar dryer with a moisture adsorbent, the highest drying rate was observed in the sample without sucrose and with 2% cinnamon, while the sample with 30% sucrose and 0.5% cinnamon had the lowest drying rate, all at a 5% error level. Furthermore, the direct sun drying (e) method showed a significantly lower drying rate compared to the solar dryer. In this direct drying method, the prolonged drying time and the higher concentration of dissolved compounds like cinnamon and sucrose resulted in a reduction of the drying rate. For example, the drying rate of the sample treated with 2% cinnamon was 153 g water/h, while this value was 193 g water/h for the apple slices treated with 0.5% cinnamon. In summary, the presence of a moisture adsorbent in the indirect solar drying method increased the drying rate, while the higher concentrations of cinnamon and sucrose in the direct sun drying method decreased the drying rate of the apple samples**.** It can be concluded that at the beginning of the drying process, the drying rate was high, and this high evaporation rate led to the formation of the surface hardening (case hardening) phenomenon, consequently, not allowing for further water removal. This occurred as the sugar diffusion from the center of the apple slices to the surface, along with water removal, resulted in the accumulation of these compounds on the surface, causing the hardening of the surface layer of the apple fruit. Additionally, in the samples containing cinnamon, a higher drying rate was observed due to the absence of sucrose. Furthermore, sucrose itself acts as a moisture adsorbent, increasing the bound water

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content, and consequently, the drying rate decreased. The results of the current research align with those of [27] and [28] , as these researchers indicated that solar drying leads to greater moisture removal. Additionally, the findings align with those of , which showed a decrease in moisture removal from the fruit with an increase in cinnamon extract concentration [29]. However, the results do not align with those of (Pashazadeh et al., 2020) [30]. Therefore, it can be generally concluded that the presence of cinnamon in the indirect drying method, with or without a moisture adsorbent, leads to a greater increase in the drying rate of the dried apple samples.

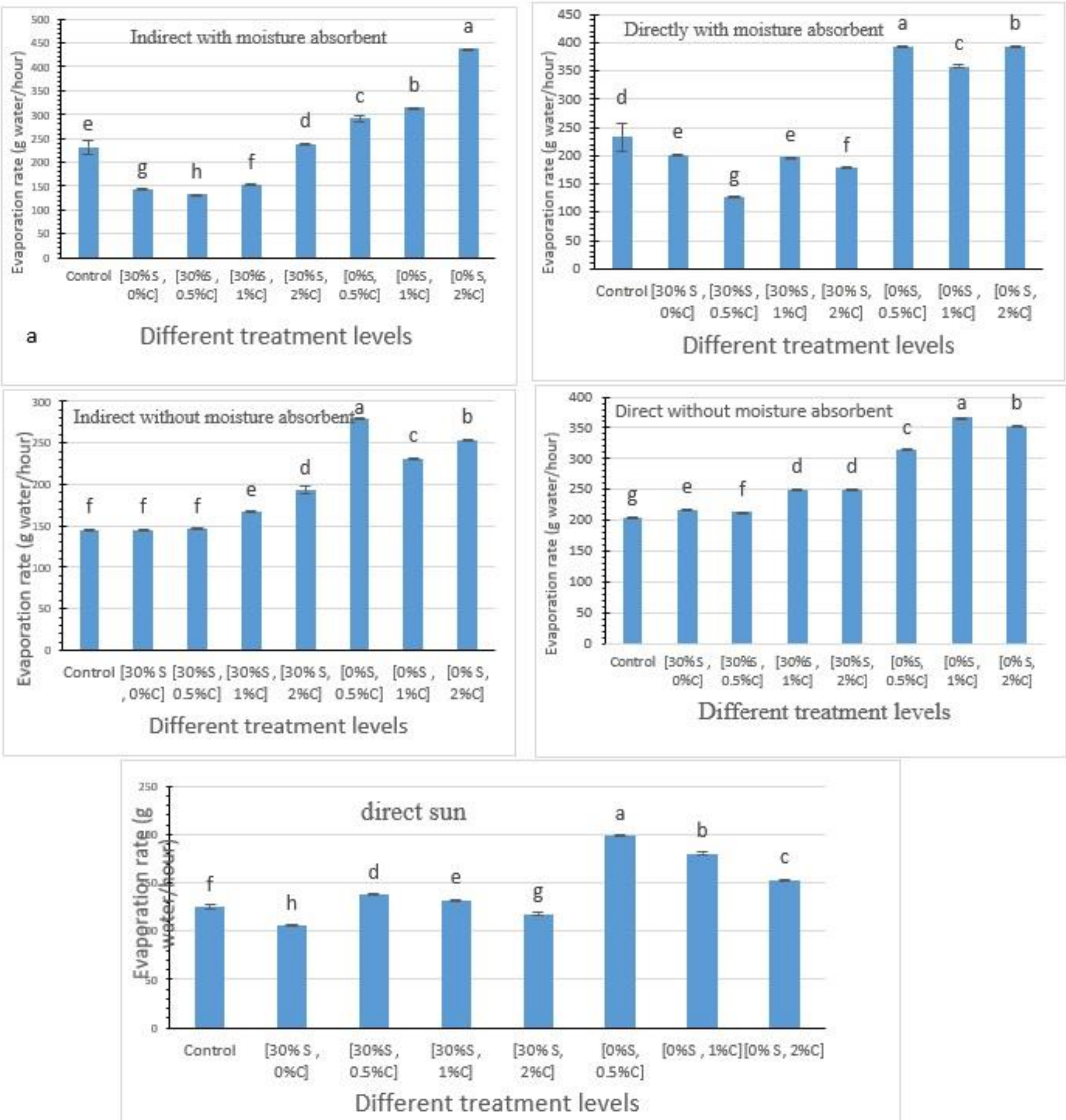

FIG 2: Evaporation rate in grams of water per hour in apple samples dried in different concentrations of sucrose and cinnamon by direct solar drying (with and without moisture absorber), indirect (with and without moisture absorber) and .traditional method (p<۰/۰۵)

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3-2- Tissue analysis

The results of the analysis of the firmness of the dried apple samples using the direct and indirect methods, with and without a moisture adsorbent, are presented in Figure 3. At first glance, for both types of drying, the firmness decreased with increasing cinnamon concentration in the samples without sucrose. The firmness of the dried apple samples with an adsorbent and containing 0.5%, 1%, and 2% cinnamon was 25.9, 98.5, and 5.5 N, respectively, and a statistically significant difference was observed between the different concentrations of cinnamon. It is likely that the increased concentration of cinnamon was accompanied by an increase in the elastic properties of the apple slices. Additionally, the increase in cinnamon concentration in the samples with 30% sucrose was also associated with a decrease in firmness. Specifically, the firmness of the sample dried with an adsorbent containing 1% cinnamon was 39.3 N. The trend of firmness changes in the samples dried without an adsorbent was similar to those dried with an adsorbent. Furthermore, the firmness of the control sample in the traditional method was significantly higher than in the other solar drying methods.

The firmness of the dried apple samples was measured, and the results showed that the firmness of the sample with 0.5% cinnamon was 29.8 N. The firmness of the control samples dried directly and indirectly, with and without an adsorbent, was 4.54, 6.06, 5.85, and 4.52 N, respectively. Overall, the firmness of the samples dried using the traditional method and at different concentrations of cinnamon and sucrose was not of a quality comparable to that of the solar drying method. Therefore, it can be concluded that adding sucrose to the apple samples before drying can have a positive effect on the relative texture. This effect is more pronounced in samples dried using the direct method. Additionally, cinnamon, which increases the elastic properties, increases the firmness of the samples, which is consistent with the findings of [31] and [23] and [32] regarding the increase in shelf life and improvement in texture with the addition of cinnamon to apple slices. This may be due to the antimicrobial properties of cinnamon, as noted by researchers such as [33].

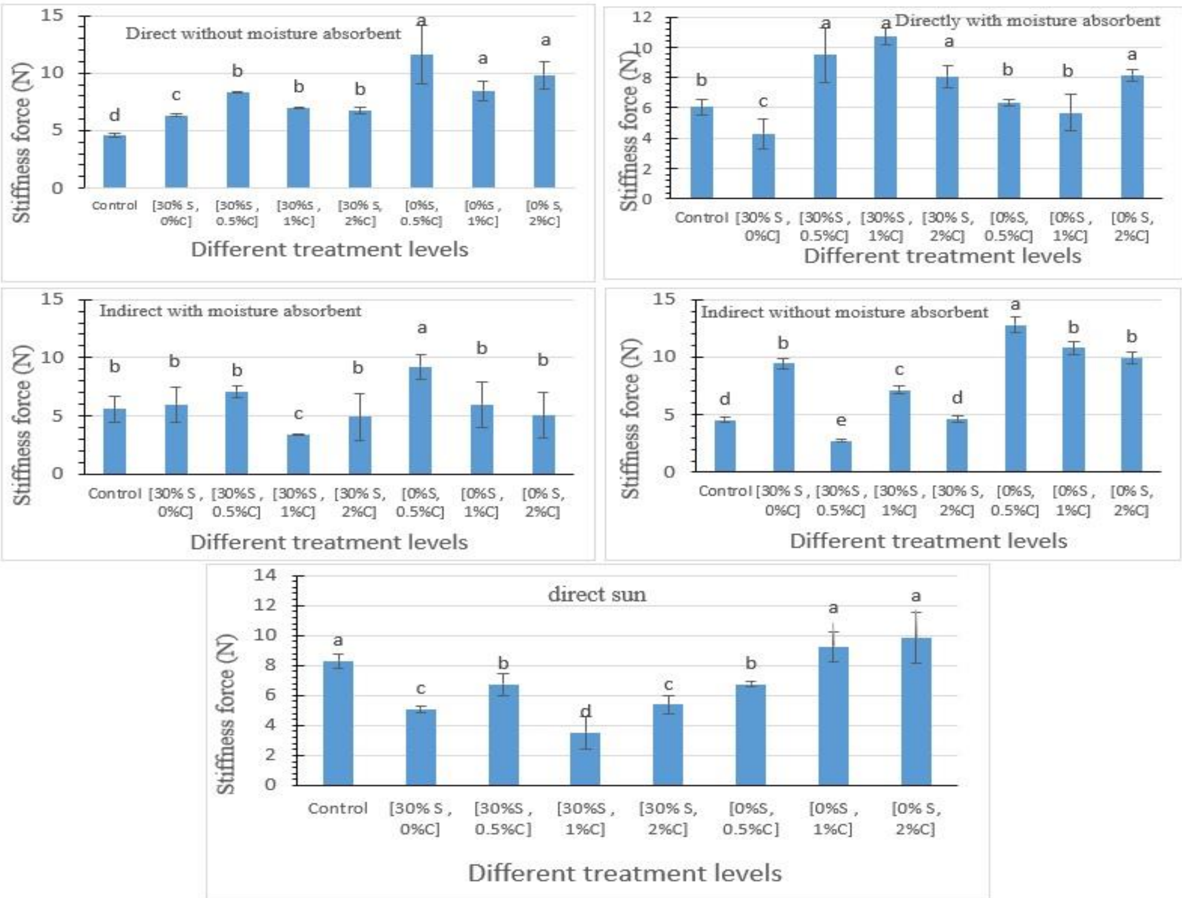

FIG 3: Changes in hardness in Newtons in apple samples dried in different concentrations of ucrose and cinnamon by direct solar drying (with and without moisture absorber), indirect (with and without moisture absorber) and traditional method p<۰/۰۵)

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3-3-Wrinkle analysis

The results of the comparison of the mean shrinkage of the dried apple samples using direct and indirect solar drying methods, with and without a moisture adsorbent, are shown in Figure 4. The findings indicate that the samples containing sucrose have lower shrinkage. Specifically, the shrinkage of the samples dried using the method without an adsorbent and containing 0.5%, 1%, and 2% cinnamon was 29.09%, 32.87%, and 34.73%, respectively, while the shrinkage of the samples containing 30% sucrose with the same cinnamon concentrations was 11.19%, 12.99%, and 19.11%, respectively. The same trend was observed in the apple samples dried with an adsorbent, where increasing the sucrose concentration led to a decrease in shrinkage. In this method, the shrinkage of the control sample was 33.47%, and the sample containing 30% sucrose and 1% cinnamon had a shrinkage of 20.35%. These results suggest that the osmotic dehydration of the apple samples in sucrose improved the structure of the apple slices. It is possible that the presence of sucrose strengthened the moisture-absorbing properties of the fruit samples and prevented the sudden removal of water from the apple slices and the formation of shrinkage in the capillary spaces.

The results of the shrinkage in the dried apple samples using the indirect method also indicate that in the samples without sucrose, the shrinkage is higher. For example, the shrinkage of the apple slices dried using the indirect method without an adsorbent for cinnamon with a concentration of 1%, the control sample, and the sample without cinnamon and with 30% sucrose was 36.46%, 29.96%, and 22.11%, respectively. In the indirect method with an adsorbent, increasing the sucrose concentration also improved the structure of the fruit after drying. In the direct sun drying method, despite the long drying time, sucrose still contributed to the improvement of the structural network. The shrinkage of the sample with 30% sucrose was 13.84%, which, compared to the control sample with 36.05%, showed a reduction of about 64%. Therefore, it can be concluded that in the traditional method, at least sucrose leads to the maximum reduction in shrinkage in the dried apple samples. The results of the current research are consistent with the findings of [34] and [35] regarding the reduction in shrinkage of apples in the indirect drying method. Additionally, the results align with the findings of that [36] the presence of sugar compounds reduces surface wrinkles.

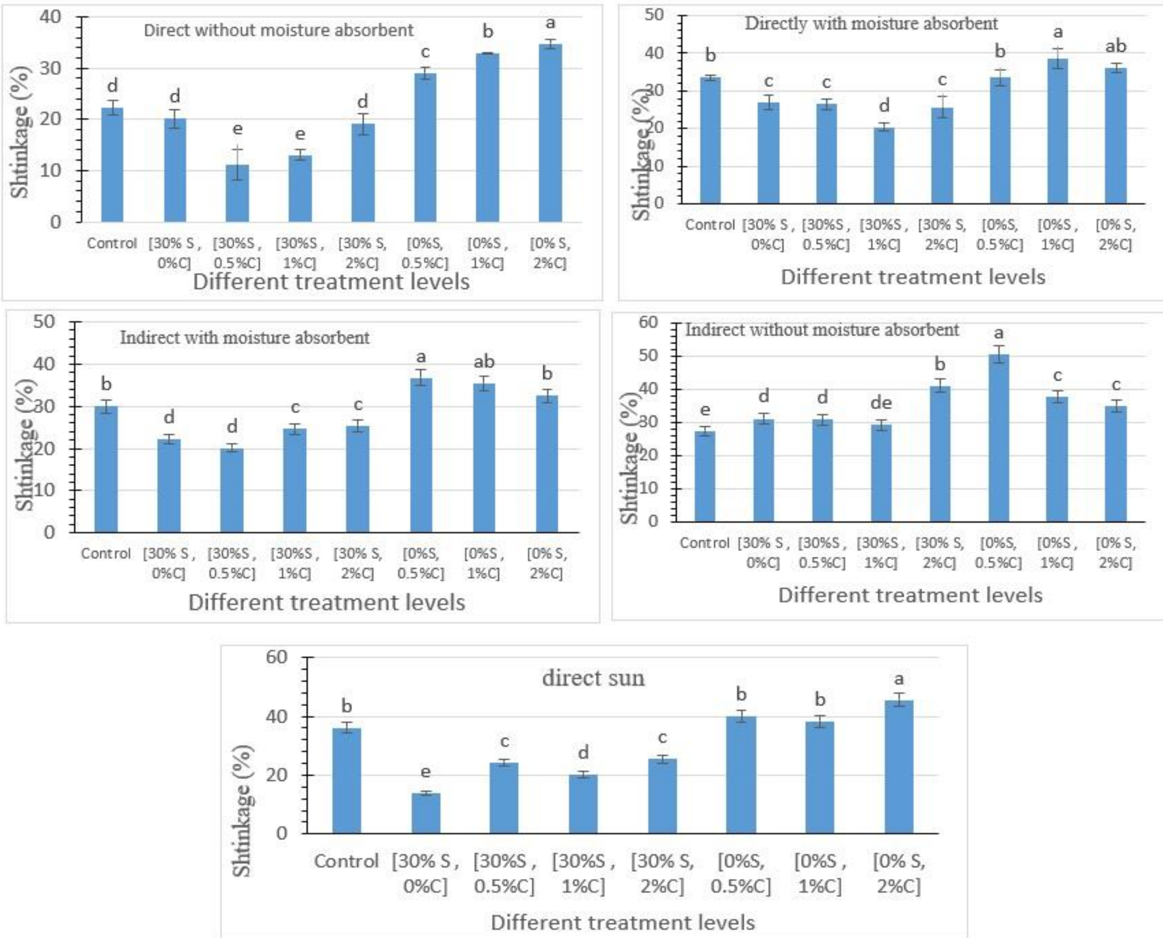

FIG 4: Changes in the amount of shrinkage in percentage in apple samples dried in different concentrations of sucrose and cinnamon by direct solar drying (with and without moisture absorber), indirect (with and without moisture absorber) and .traditional method (p<۰/۰۵)

3-3- Reabsorption analysis

The results of the comparison of the rehydration capacity of the dried apple samples using direct and indirect solar drying methods, with and without a moisture adsorbent, are presented in Figure 5. The findings indicate that overall, the samples containing sucrose had a more favorable rehydration capacity. Specifically, the rehydration capacity of the samples dried using the method without an adsorbent and containing 0.5%, 1%, and 2% cinnamon was 29.64%, 35.29%, and 29.47%, respectively, while the rehydration capacity of the samples containing 30% sucrose with the same cinnamon concentrations was 41.51%, 43.43%, and 74.41%, respectively. In the samples dried with an adsorbent, the same trend was observed, with increasing sucrose concentration leading to an increase in rehydration capacity. The rehydration capacity of the control sample, the sample containing 30% sucrose and 1% cinnamon, and the sample without sucrose and 2% cinnamon was 41.09%, 39.82%, and 31.58%, respectively. The comparison of the rehydration capacity results with the analysis of shrinkage in the different samples confirms that the presence of sucrose in the apple slices helps maintain the physical structure and reduces shrinkage, which in turn leads to better rehydration capacity in the dried samples. Additionally, in the direct sun drying method, the samples containing sucrose and the control sample had more favorable rehydration capacity compared to the samples with different concentrations of cinnamon. It can be concluded that, given the long drying time in this method, the presence of cinnamon through the creation of adhesive properties may have contributed to the reduction of structural stability in the dried samples. In the indirect method, increasing the sucrose concentration also led to a reduction in shrinkage and an improvement in rehydration capacity, ultimately leading to [36] an improvement in the structure of the fruit after drying. This is consistent with the findings of regarding the increase in rehydration capacity with increasing sucrose concentration in fruit [37].

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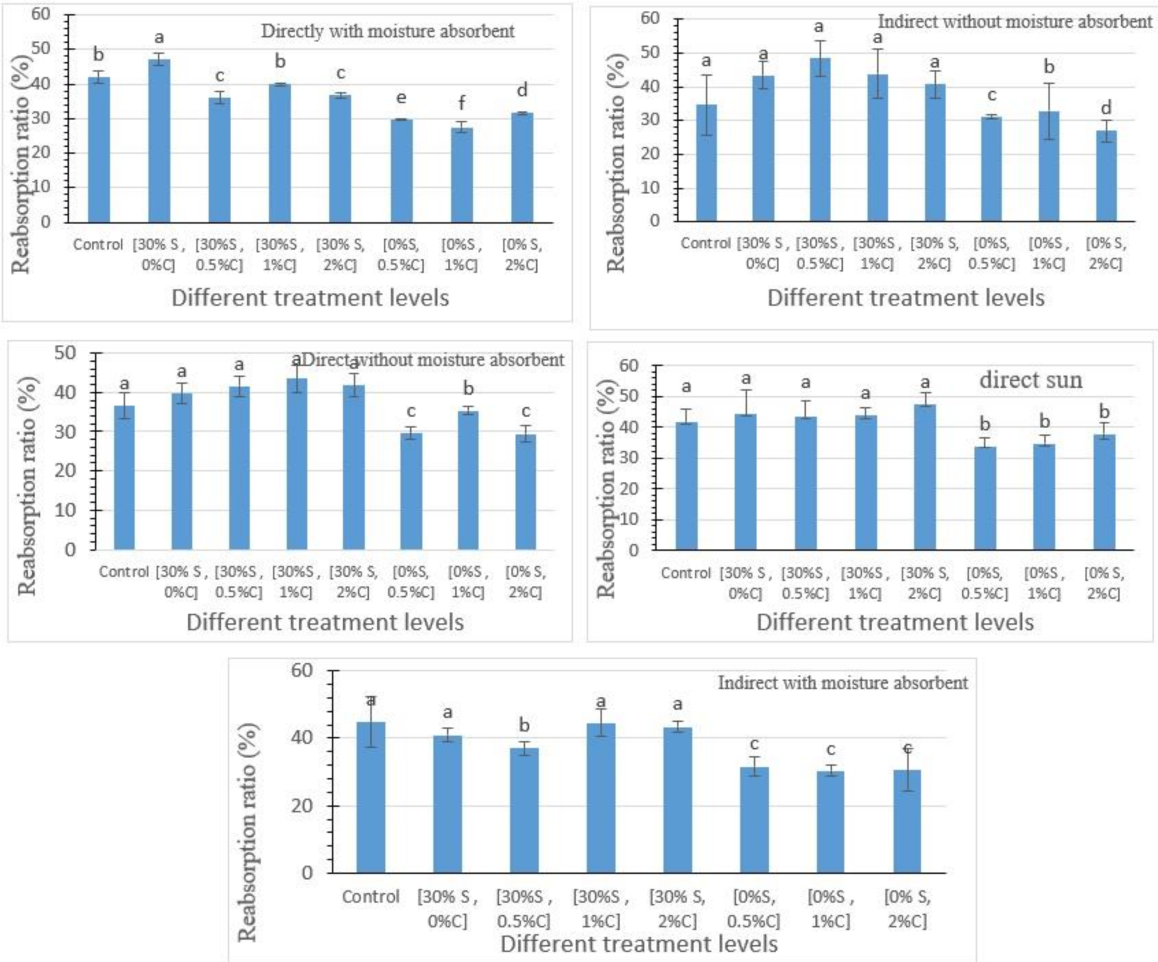
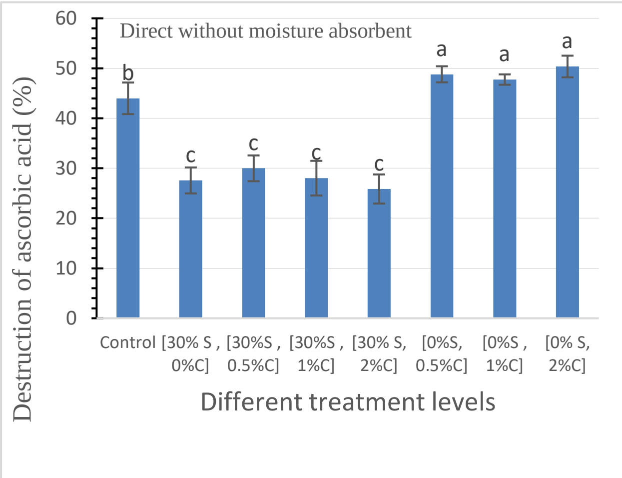
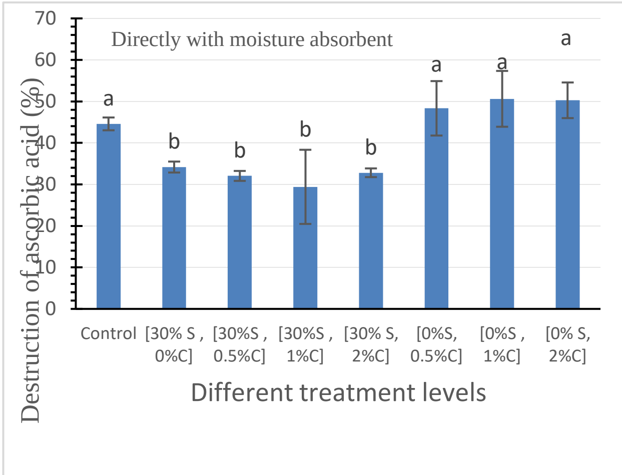


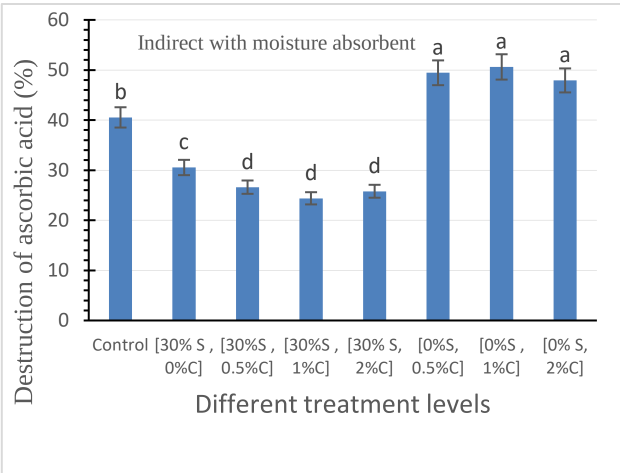
FIG 5: Changes in the amount of water absorption in percentage in apple samples dried in different concentrations of sucrose and cinnamon by direct solar drying (with and without moisture absorber), indirect (with and without moisture .absorber) and traditional method (p<۰/۰۵)

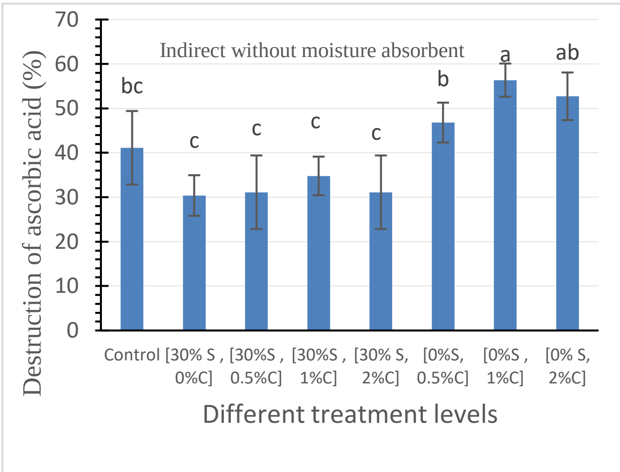
3-4- Analysis of vitamin C degradation rate

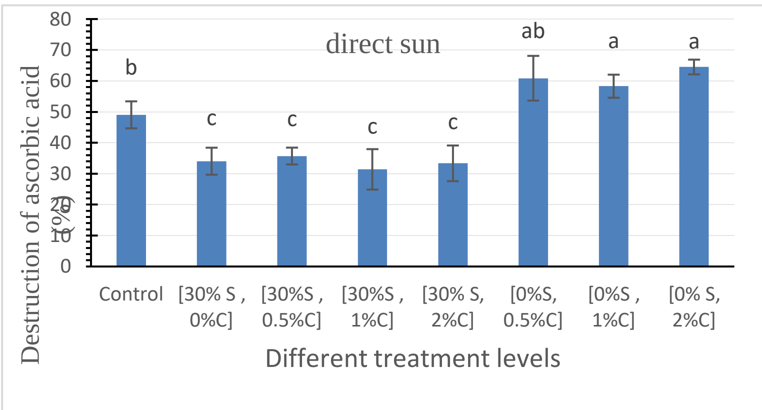
The results of the comparison of the average vitamin C degradation in the dried apple samples using direct and indirect solar drying methods, with and without a moisture adsorbent, are presented in Figure 6. The analysis of the data indicates that the use of sucrose improves the preservation of vitamin C, and the degradation of vitamin C in these samples is lower compared to the control samples and those with different concentrations of cinnamon. For example, the degradation of vitamin C in the sample dried with an adsorbent for apple slices immersed in a 30% sucrose solution and 0.5% cinnamon was 32.04%, while in the control sample and the sample with 0.5% cinnamon, the degradation was 48.33% and 44.58%, respectively, which shows a significantly lower preservation of vitamin C. As observed in [38], the treatment with an osmotic solution can improve the preservation of vitamin C by reducing the rate of diffusion of vitamin C out of the fruit. Additionally, as previously observed, in the samples containing sucrose, a sugar layer forms on the surface of the fruit, which can have a significant effect in preserving vitamin C within the fruit by preventing its release to the surface. The preservation of vitamin C in the samples dried directly without an adsorbent was also higher in the treated samples with sucrose. Overall, the control samples or those treated without sucrose showed the same level of vitamin C degradation. However, the degradation of vitamin C in the samples treated with cinnamon was higher than in the control sample. For example, the degradation of vitamin C in the sample dried with an adsorbent in the direct method was 44.58%, while in the sample treated with 2% cinnamon, it was 50.26%, which shows a significant difference from the control sample. The reason for this difference is due to the preparation method of the cinnamon samples, where the apple slices were immersed in different concentrations of cinnamon for 2 hours at 40°C. It is predicted that the degradation of vitamin C at this temperature contributed to this significant difference. In the end, adding cinnamon at different levels did not show a consistent trend for vitamin C degradation. Additionally, the degradation of vitamin C in the direct sun drying method was higher compared to the other drying methods. The results of the current research are consistent with [39] the findings of regarding the reduction in vitamin C degradation in the indirect drying of tomatoes and mangoes and [38]. It can be stated that vitamin C is one of the most important plant chemical compounds and is found in almost all fruits and vegetables. Since it covers almost all possibilities, including minerals in water and prone to washing out of cells, sensitive to heat (one of the most sensitive vitamins), pH-, metal ions, sensitive to light, and easily oxidized by ascorbic acid oxidase, and vitamin C is the most commonly measured nutritional compound for evaluating the loss of nutrients during thermal processing. On the other hand, sucrose, with its characteristic of preserving moisture [40], plays a significant role in preserving vitamin C due to its aqueous solution composition.











[DOI: 10.22034/FSCT.21.154.107]

FIG 6: Changes in vitamin C degradation in dried apple samples in different concentrations of sucrose and cinnamon by direct solar drying (with and without moisture absorbent), indirect drying (with and without moisture absorbent) and traditional method (p<۰/۰۵)

3-5- Color change analysis (ΔE)

The results of the comparison of the average color change (ΔE) are presented in Figure 6. The results indicate that a higher ΔE value represents greater color change, and the sample has a darker color (tending towards brown) [41]. The results of the comparison of the average ΔE (total color change) in the direct drying method with and without an adsorbent generally show that the samples containing sucrose had more favorable conditions in both methods, and they had better color quality compared to the control samples and those containing cinnamon. In the comparison between the control and the samples containing cinnamon, the samples with cinnamon had less desirable color conditions. For example, the color change (ΔE) of the samples with 30% sucrose and 0.5% cinnamon in the direct drying method without an adsorbent and with an adsorbent was 13.34 and 11.72, respectively, while for the control samples in both methods it was 18.88 and 22.25, respectively. The color change (ΔE) for the samples dried using the direct method without an adsorbent and containing 0.5%, 1%, and 2% cinnamon was 25.44, 25.95, and 27.95, respectively, and in the direct method with an adsorbent, it was 24.31, 27.51, and 28.72, respectively. Additionally, since cinnamon itself has a brown color, it intensified the color in these samples. Comparing the two direct drying methods, with and without an adsorbent, the conditions were more favorable in the method with an adsorbent, meaning that the moisture removal in this method resulted in better quality. It can be concluded that the moisture removal in the drying methods with an adsorbent reduced the activity of polyphenol oxidase and phenol oxidase enzymes, ultimately leading to a decrease in enzymatic browning. The results of the current research align with the findings of [42]. In the indirect drying method, since the samples are dried by hot air and are not exposed to direct sunlight, it has resulted in more favorable color conditions for the samples. For example, the control sample in the indirect method had a more suitable color compared to the direct method, and its ΔE value was lower. In this method, the samples containing sucrose also showed more favorable drying conditions, and the ΔE value increased in the samples containing cinnamon.

In the direct sun drying method, the same trend as the solar dryer was observed, and despite the longer drying time, the samples containing sucrose showed favorable conditions. The results of this research are consistent with the findings of researchers such as [43], who reported the positive effect of sucrose in maintaining moisture and reducing color changes in dried fruits, and , as [44], the results show that color and microstructure can be preserved, bulk density can be reduced, and high rehydration capacity can be achieved by using better drying methods. In summary, the indirect drying method resulted in more favorable color conditions compared to the direct sun drying, and the presence of sucrose helped maintain the color of the dried apple samples better, while the addition of cinnamon led to greater color changes, regardless of the drying method used.

[DOI: 10.22034/FSCT.21.154.107]

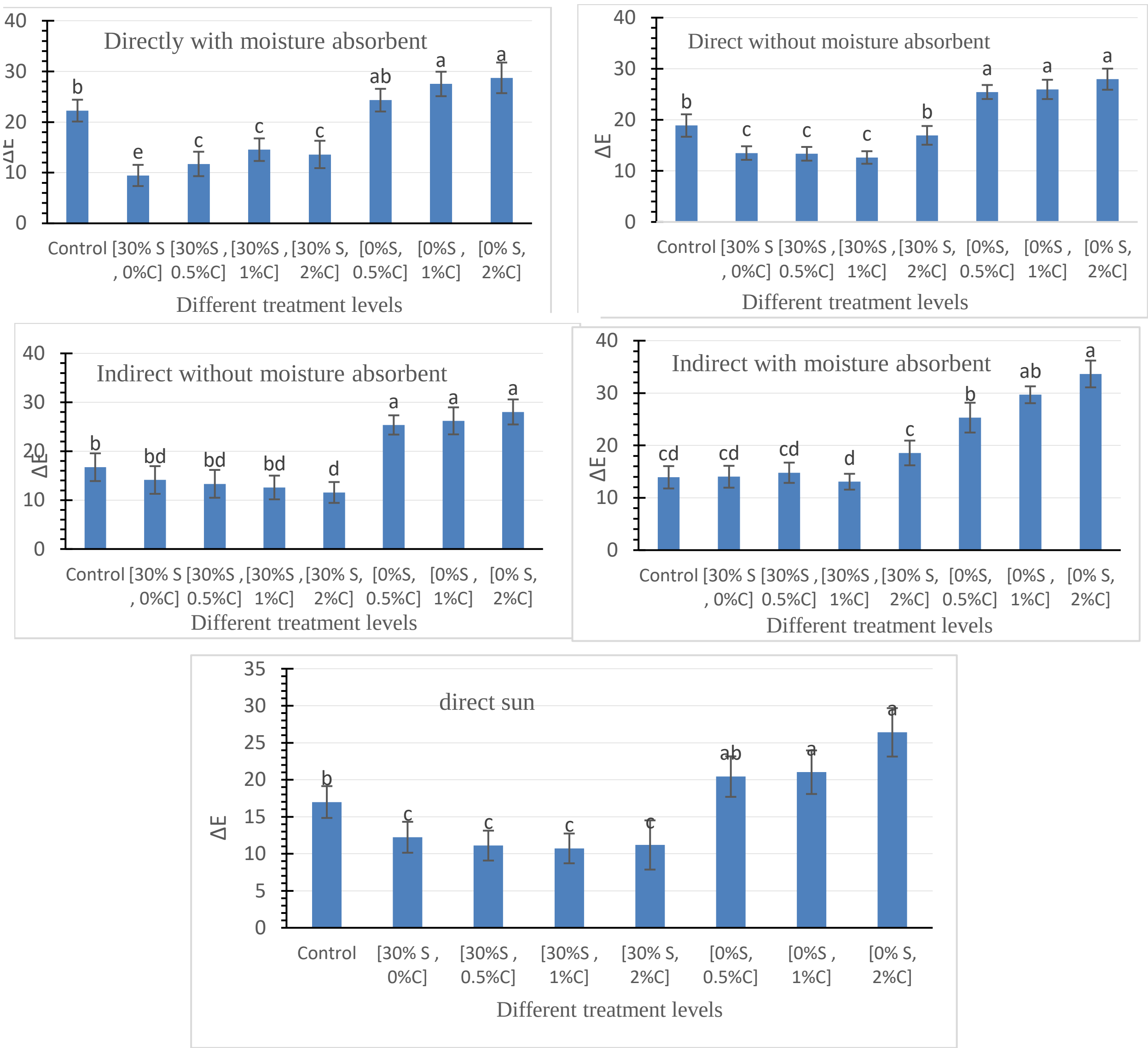


FIG 7: Changes in the amount of color change (ΔE) in apple samples dried in different concentrations of sucrose and cinnamon by direct solar drying (with and without moisture absorber), indirect (with and without moisture .absorber) and traditional method ($p<0.05$)

[DOI: 10.22034/FSCT.21.154.107]

3-6- Sensory evaluation analysis (color, smell, texture, taste and overall acceptance)

The results of the sensory evaluation conducted by the panelists on the direct solar drying method with and without a moisture adsorbent are presented in Figure 7. The evaluation was based on a 5-point hedonic scale, where a higher score closer to 5 indicates greater acceptability from the panelists' perspective, and lower scores closer to 1 indicate poor quality. The results regarding color show that the samples containing sucrose had greater color acceptability, while the samples without sucrose and containing cinnamon had the lowest acceptability from the panelists' perspective. The calculation of the ∆E parameter also confirmed that the presence of sucrose improved the color of the dried samples. The lowest color acceptability was related to the apple samples dried with different concentrations of cinnamon and without sucrose, and their acceptability was lower than the control sample. Comparing the different drying methods, the indirect solar drying method with an adsorbent had the highest acceptability, while the direct sun drying method had the lowest color acceptability among the panelists. The results of the sensory evaluation of aroma indicate that before consuming the apple slices, the panelists evaluated the aroma and scored it from 1 to 5. The results show that the samples containing sucrose and cinnamon received the highest scores. For example, the sample immersed in a solution of 2% cinnamon and 30% sucrose received the highest score. However, the samples with 2% cinnamon and without sucrose received the lowest aroma scores. It can be concluded that sucrose had a preservative effect on cinnamon during drying, and the samples prepared with these treatments still had a mild release of cinnamon after drying. But the samples prepared with cinnamon and without the osmotic solution could not attract the panelists' attention regarding the olfactory pleasure of cinnamon in the dried apples. The results of the sensory evaluation of texture also showed that the highest scores were given to the samples containing sucrose, and they were considered to have an acceptable texture from the panelists' perspective. However, the samples treated with cinnamon and without sucrose had lower acceptability. These samples were perceived by the panelists as brittle and firm, and there was no significant difference between the different drying methods in terms of texture. The results of the sensory evaluation of taste and flavor also show that the samples containing sucrose had greater flavor acceptability, while the samples without sucrose and containing cinnamon had the lowest acceptability from the panelists' perspective. Additionally, the samples with 30% sucrose and 0.5%, 1%, and 2% cinnamon received the highest scores, i.e., the greatest acceptability in terms of flavor. It should be noted that in these samples, both the presence of sucrose as a sweet taste and the presence of cinnamon flavor were desirable for the panelists. Comparing the different drying methods, the apples prepared by the indirect drying method without an adsorbent had the highest acceptability among the panelists. The results of the overall acceptance sensory evaluation indicate that the samples containing sucrose and different concentrations of cinnamon received the highest scores. Specifically, the sample with 30% sucrose and 2% cinnamon was the most preferred among all the samples. Additionally, the indirect drying method with and without an adsorbent had the highest acceptability in terms of texture and overall acceptance.

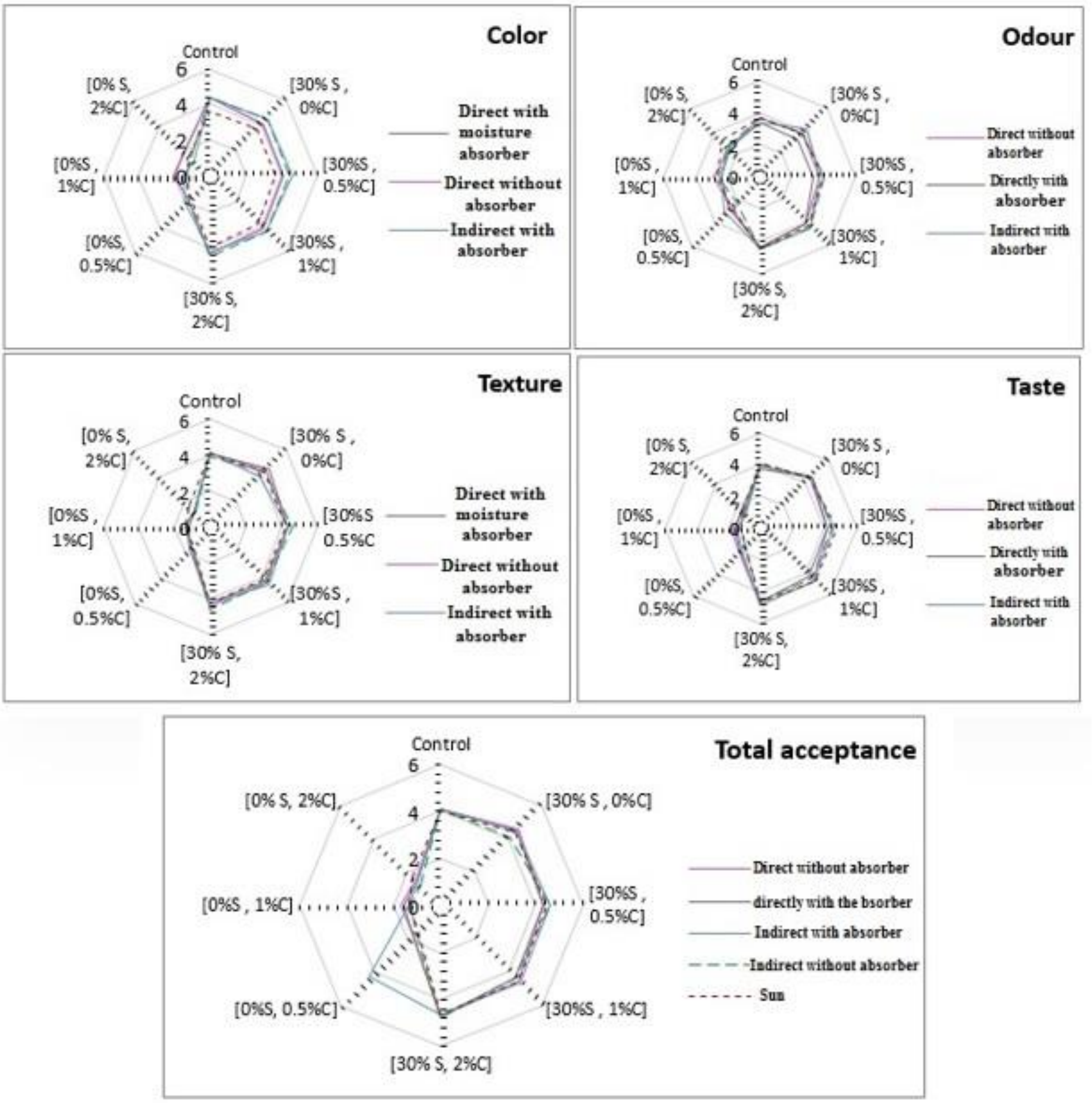


FIG 8: Sensory evaluation of dried apple samples in different concentrations of sucrose and cinnamon by direct solar drying .(with and without moisture absorber), indirect (with and without moisture absorber) and traditional method (p<۰/۰۵)

3-7- Conclusion

In this study, apple samples were dried using various methods, including direct and indirect solar drying, and without a moisture adsorbent. Different concentrations of cinnamon were also used. The results showed that in the direct drying method without a moisture adsorbent, the moisture removal rate was higher in the samples without sucrose (1% cinnamon) compared to the samples containing sucrose and cinnamon. Additionally, the moisture removal in the control sample of the direct drying method without an adsorbent was lower compared to the other treatments. Comparing the control samples in the direct drying method with and without a moisture adsorbent, the evaporation rate was significantly higher in the samples with the adsorbent. Comparing the samples containing sucrose between the direct drying methods with and without a moisture adsorbent, the samples with the adsorbent had a lower evaporation rate. In the direct sun drying method, the drying rate was significantly lower compared to the solar dryer. The results of the evaporation rate of the apple samples in the indirect drying method also showed that, similar to the direct method, the evaporation rate of the samples with cinnamon treatment but without sucrose was higher than the evaporation rate in the samples with sucrose and the control. This was attributed to the accumulation of sugars on the fruit surface, and the increase in the concentration of dissolved compounds such as cinnamon and sucrose led to a decrease in the drying rate. The structural characteristics and texture analysis in the direct drying method showed that the highest firmness was observed in the direct drying method without an adsorbent for the samples without sucrose and with different levels of cinnamon (maximum at 5%), with no significant difference. The firmness of the samples treated with sucrose along with cinnamon showed a significant difference compared to the control sample, and the firmness increased compared to the control group. In summary, the presence of sucrose and cinnamon affected the drying rate, texture, and color of the dried apple samples, with the indirect drying method generally showing better results. In this way, it can be stated that the firmness in the drying method with a moisture adsorbent for the samples containing sucrose was higher than the firmness of the same samples in the drying method without an adsorbent. The reason for this can be attributed to the phenomenon of surface hardening, which is due to the presence of sucrose. The texture analysis in the indirect drying method also showed that cinnamon increases the firmness in the dried samples without a moisture adsorbent, and the reason for this is the increase in the elastic properties of the apple slices with an increase in the concentration of cinnamon. The investigation of the structural characteristics and shrinkage analysis in the direct drying method showed that the samples containing sucrose had lower shrinkage, and with an increase in the concentration of cinnamon, the shrinkage increased, with the maximum increase observed in the direct drying method without an adsorbent at 2% cinnamon and in the direct drying method with an adsorbent at 1% cinnamon. Additionally, the results of the shrinkage analysis in the indirect drying method showed that the samples without sucrose had higher shrinkage, which is due to the lack of structural improvement in the capillary networks. The investigation of the rehydration capacity in the direct and indirect drying methods also showed that the samples containing sucrose had more favorable rehydration conditions, and different concentrations of cinnamon caused a decrease in rehydration. The results related to the degradation of vitamin C in the direct drying method showed that the use of sucrose improved the preservation of vitamin C, while different concentrations of cinnamon caused the degradation of ascorbic acid. The analysis of color change in the direct and indirect drying methods also showed that the samples containing sucrose had more favorable conditions in both methods, and cinnamon caused greater color changes

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خشک‌کردن سیب با استفاده از خشک‌کن خورشیدی با چرخه جاذب در دو حالت تابش مستقیم –همرفتی و غیرمستقیم–همرفتی

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چکیده

هدف: هدف از پژوهش حاضر خشک‌کردن سیب با استفاده از خشک‌کن خورشیدی با چرخه جاذب در دو حالت تابش مستقیم –همرفتی و غیرمستقیم-همرفتی می‌باشد. از دو نوع روش خشک کردن مستقیم و غیرمستقیم با جاذب و بدون جاذب رطوبت و خشک کردن در هوای آزاد استفاده شد. ورقه‌های سیب آماده‌شده از قبل (طعم دار شده با دارچین) روی یک قطعه توری با ابعاد مشخص قرار گرفت، وزن اولیه نمونه‌ها اندازه‌گیری و در داخل خشک‌کن خورشیدی با چرخه جاذب در دو حالت تابش مستقیم –همرفتی و غیرمستقیم–همرفتی، گذاشته شد؛ و طی فرایند خشک شدن سرعت تبخیر، بافت، چروکیدگی، میزان بازجذب آب، میزان حفظ ویتامین C (آسکوربیک اسید) و تغییر رنگ و خصوصیات حسی در سطوح مختلف تیمار (۳۰ درصد ساکارز و بدون ساکارز و صفر، ۰/۵، ۱ و ۲ درصد دارچین) بررسی و همچنین چند نمونه به‌عنوان شاهد بدون طعم‌دار کردن با دارچین به‌تنهایی توسط خشک‌کن خورشیدی خشک شد. تجزیه و تحلیل داده‌ها با روش آماری طرح فاکتوریل کاملاً تصادفی و استفاده از نرم‌افزار آماری SPSS نسخه ۲٦ صورت گرفت. نتایج حاصل از پژوهش نشان داد که در روش مستقیم و غیرمستقیم، با و بدون جاذب رطوبت نرخ حذف رطوبت در نمونه‌های بدون ساکارز نسبت به نمونه‌های دارای ساکارز و دارچین بیشتر می‌باشد و مقایسه نمونه‌های کنترل در دو روش مذکور با و بدون جاذب رطوبت نشان می‌دهد که سرعت تبخیر نمونه‌ها در جاذب رطوبت به صورت معنی‌دار بیشتر است. علاوه بر این در نمونه‌های دارای ساکارز در روش دارای جاذب رطوبت سرعت تبخیر پایین‌تر می‌باشد و در روش مستقیم آفتاب در مقایسه با خشک‌کن خورشیدی به صورت معنی‌داری سرعت خشک‌کردن پایین آمده و نتایج سرعت تبخیر در روش خشک‌کردن غیرمستقیم نیز نشان داد که همانند روش مستقیم، نرخ تبخیر نمونه‌های دارای تیمار دارچین و فاقد ساکارز بیشتر از نرخ تبخیر در نمونه‌های دارای ساکارز و کنترل می‌باشد. نتایج آنالیز بافت نیز حاکی از آن بوده؛ بیشترین میزان سفتی در روش مستقیم بدون جاذب برای نمونه‌های بدون ساکارز با میانگین‌های فاقد اختلاف معنی‌دار است. همچنین دارچین سبب افزایش نیروی سفتی در نمونه‌های بدون جاذب رطوبت در روش خشک‌کردن غیرمستقیم شد و نمونه‌های دارای ساکارز میزان چروکیدگی کمتری داشته و با افزایش غلظت دارچین میزان چروکیدگی افزایش و بیشترین افزایش در روش مستقیم بدون جاذب در مقادیر ۲ درصد دارچین و در روش مستقیم با جاذب در غلظت ۱ درصد دارچین مشاهده شد. بررسی میزان باز جذب آب نیز در روش‌های خشک‌کردن مستقیم و غیرمستقیم نشان داد که نمونه‌های دارای ساکارز شرایط باز جذب آب مطلوب‌تری داشته و میزان تخریب ویتامین C نیز نشان داد که استفاده از ساکارز سبب بهبود حفظ ویتامین C می‌شود و آنالیز تغییر رنگ نیز حاکی از آن بوده که نمونه‌های دارای ساکارز در هردو روش شرایط مناسب‌تری دارند. بنابراین نتایج مربوط به ارزیابی خصوصیات حسی نشان داد نمونه‌هایی که دارای ساکارز و غلظت‌های مختلف دارچین بوده‌اند، بیشترین نمره ارزیابی را دریافت کرده‌اند. فلذا می‌توان بیان کرد که نمونه‌هایی که با محلول اسمزی و ساکارز خشک شده‌اند به طورکلی مقبولیت بیشتری هم از لحاظ فیزیکی و هم رنگ، طعم و مزه داشته‌اند.