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SCIENTIFIC PAPER

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EFFECTS OF PRETREATMENTS ON DRYING OF TURKEY BERRY (*Solanum torvum*) IN FLUIDIZED BED DRYER

Article Highlights

- The combined pretreated drying process exhibits enhanced drying kinetics of the fruits
- The pretreated drying process resulted in improved qualities of the fruits
- Enhance the character of heat and mass transfer by both physical and chemical treatments

Abstract

The influence of pretreatment methods like physical, chemical, combined physical, and hybrid treatments on the Turkey berry (Solanum torvum) fruits to enhance the water diffusion during drying was assessed due to removing a waxy layer on the peel. Pretreated and untreated samples were dried at 70 ºC and 4 m/s of air flow in a fluidized bed dryer. Fruits pretreated with combined abrasion and blanching have the lowest drying time and good vitamin C content retention of 36%. The highest drying rate of 0.396 kg water/kg$_{db}$ min^{-1}, maximum effective moisture diffusivity of 6.002 x 10^{-10} m^2/s, and volumetric shrinkage ratio of 0.68 were obtained for fruits that undergone combined physical pretreatment along with drying. The maximum change in color ΔE = 14.75 and Chroma ΔC = - 10.53 were obtained for the untreated samples.

Keywords: color, effective moisture diffusivity, pretreatment, shrinkage, Turkey berry, vitamin C.

Turkey's berry fruits are like green peas that grow in clusters of tiny green spheres, identified as *Solanum torvum* in the family of Solanaceae. Every hundred grams of young Turkey berry fruit are a good source of important micro-nutrients, like 104 mg Ca, 70 mg P, 4.6 mg Fe, 390 µg β-carotene, and 4 mg ascorbic acid, as well as 85.4 g of water [1]. However, this fruit quickly deteriorates with spoilage and thus needs techniques for conservation.

The high moisture content of agri-food-stuffs makes it difficult to preserve for a long time. Removing the water content by drying extends the self-life of those products. As a result, it prevents the growth and reproduction of microorganisms [2-4]. Furthermore, food-stuffs are susceptible to drying environments such as processing temperature, inlet fluid flow, relative humidity that can lead to the quality degradation of the products by oxidation, changes in color, and loss of physical and biochemical properties [5].

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Drying significantly decreases food-stuff weight and volume and brings many advantages such as reducing packaging and transport cost and storage space [2-4]. Commercially many kinds of dryers were available in the market like convection dryer, fluidized bed dryer, microwave dryer, drum dryer, freeze dryer, solar dyer, infra-red radiation dryer, etc. Fluidized bed drying has been widely used to dry food products [6].

Fluidized bed drying, which considerably eliminates the water content from the sample with a high degree of thermal efficiency, has been recognized for uniform drying with excellent heat and mass transfer [7-8]. Also, FBD is a convenient method that avoids overheating food products that are heat sensitive. It has been stated that pretreatment of agri-food-stuffs before dehydration can improve the drying kinetics and minimize unnecessary changes in physical and biochemical properties like color, texture, shrinkage, micro-neutrinos, etc. [2].

The drying of Turkey berry fruits is restricted by a waxy skin layer similar to grapes, Cape gooseberry, plumes, and cheery fruits, preventing water movement across the peel and slowing the drying rate [5]. Agricultural food products with waxy skin have been pretreated physically, chemically, and in combination to improve drying characteristics, as has been reported by many authors [9-13].

Physical pretreatments such as blanching, skin puncturing, and surface abrasion preceding the dehydration of samples are typically intended to promote water transfer mechanisms. Blanching can be carried out either at "short-time" with a high temperature or at "long-time" with low temperatures, and its performance depends on the selection of process [9,14]. Adeletta *et al.* [5] revealed that grapes treated with skin abrasion and dehydrated at low temperatures could reduce changes in physicochemical properties. In forced convection dryer, cape gooseberry fruits pretreated by physical and chemical resulted in better final qualities and drying kinetics [9].

In this present investigation, the effects of Turkey berry's physical, chemical, combined physical, and hybrid pretreatments on drying kinetics, physical, and nutritional properties were analyzed in a fluidized bed dryer. The influence of the edible oils with varying concentrations and the soaking time was studied.

MATERIALS AND METHODS

Samples preparation

Turkey berries with 12.5 ± 0.5 mm average diameter and weighing 2 ± 0.2 g were used for the experiments. Samples were collected from the native market at Krishnagiri town of Tamilnadu, India. About 10 g of fresh fruits were taken to study the sample's initial moisture content, and the average moisture content is measured as suggested by the AOAC method [15]. From the test, the initial moisture content of fruit is observed as 84 ± 1% on a wet basis (w.b.), and each test was carried out thrice.

Pretreatment preparations

The details of the physical and chemical pretreatment processes used are listed in Table 1. Sample and solutions were prepared freshly for each treatment with a ratio of 1:2.5 (fruits: solution). Untreated (T1), two physically treated (T2 &T3), two combined physically treated (T4 &T5), four chemically treated (T6, T7, T8, and T10), and one combined physically and chemically treated (T9) were prepared.

Table 1. Pretreatment methods of samples

Treatment	Description
T1	Samples were untreated (control process)
T2[a]	Samples balanced by hot water immersion at 90 °C for 20 s
T3	Abrasive treatment 30 min at 30 rpm
T4[a]	Abrasive treatment + Hot water at 90 °C for 20 s
T5[a]	Hot water at 90 °C for 20 s + Abrasive treatment
T6	Peanut oil (9.5%) + K_2CO_3 (4.75%) 60 min
T7	Sesame oil (9.5%) + K_2CO_3 (4.75%) 60 min
T8	Sesame oil (0.5%) + K_2CO_3 (4.75%) (soaking time - 60 min)
T9[a]	Sesame oil (5%) + KOH (1.5%) 90 °C 20 s
T10	Sesame oil (0.5%) + K_2CO_3 (4.75%) (soaking time - 30 min)

[a]The samples were cooled down to room temperature by cold water until the residual surface water was extracted.

After the pretreatment processes, the fruits were cleaned with the help of tissue paper, in which water on the sample surface was absorbed. In chemical pretreatments, the fruits were immersed in solutions at an average temperature of 30 °C and stirred continuously for 60 min using a Laboratory magnetic stirrer at 300 rpm except for the T10 (Remi Laboratory Instruments, Maharashtra, India).

Abrasion of the samples T3, T4, and T5 were executed on a mechanized revolving drum with a diameter of 250 mm, length of 400 mm, and made of acrylic material with sandpaper (Grit 400) pasted inside the drum. The rotation speed of the drum was kept at 30 rpm and the pretreatment time was 30 min. The T6 and T7 processes have been conducted to examine the impact of the same chemical compound comprising two different oils. The chemical pretreatments (T7, T8, and T10) of a sesame oil solution were carried out with K_2CO_3 at various solution concentrations and soaking times. Similarly, the pretreatment T9 was carried out by KOH and sesame oil with blanching. After the pretreatment, the samples were dried at room temperature on an absorbent paper before feeding to the drying chamber.

Experimental set-up and procedure

A laboratory-scale fluidized bed dryer, as shown in Figure 1, was used to analyze the drying properties of the Turkey berry. The FBD has a centrifugal blower with a variable frequency drive controller, an electric heater, and a bag filter. The drying chamber (height 0.9 m and inner diameter 0.15 m), made of stainless steel, is connected with a truncated cone (the funnel) of a total disengagement height (TDH) of 1.2 m and a top diameter of 0.25 m. The air flew into the bed through a perforated stainless steel plate (an open area of 20 ± 0.05%) with 4.0 ± 0.01 mm diameter holes in a triangular pitch of 8.0 ± 0.02 mm. The inlet air velocity was measured with an anemometer (AM-4201) with an accuracy of 0.1 m/s. The air was heated by an electric heater and sent to the drying chamber. In all drying processes, the investigations were conducted at an inlet air temperature of 70 °C and an inlet air velocity of 4 m/s.

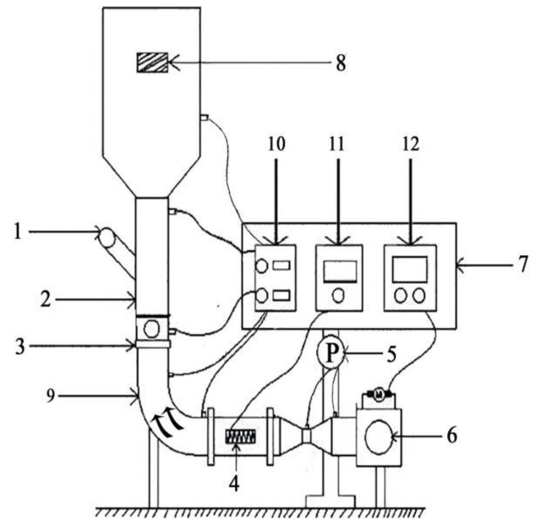

Figure 1. Schematic diagram of FBD setup: (1) inlet port (2) drying chamber (3) air distributor (4) electrical heater (5) differential pressure sensor (6) blower (7) control unit (8) filter-bag (9) plenum chamber (10) temperature indicator (11) energy meter (12) VFD controller.

The pretreated samples were placed into the drying chamber when the bed reached a stable state by controlling the temperature and the air flow rate. At time intervals of 10 min, the whole sample was unloaded from the drying chamber, and the weight was measured using a digital weighing balance (Kerro, BL5002, range 0 g - 500 g) with a reading accuracy of 0.01 g. After weight measurement, the sample was again loaded into the drying chamber for another 10 min to reduce its moisture content further. The loading of the fruits proceeded until the moisture content reduced below 14 ± 0.5% (d.b). To confirm the repeatability of the analysis, three runs were conducted for every drying process.

Response variables

The effect of physically, chemically, combined physically, and combined physiochemically pretreated fruit samples on the fluidized bed drying were evaluated by measuring the drying time and rate throughout the drying process, together with the color, shrinkage, and vitamin C.

Response variables

Drying kinetics was investigated by assessing the weight reduction of a sample with time. Drying curves can be denoted in many ways, such as variations of the moisture content and the drying rate with time or the drying rate as a function of the moisture content. The moisture content of Turkey berry is assessed on a dry basis (d.b.) using the following equation [8,16]:

$$M_{db} = \left(\frac{W_{st} - W_{dry}}{W_{dry}}\right) \tag{1}$$

The moisture ratio (MR) of Turkey berry during the drying experiments is calculated by using the following equation [11,17]:

$$MR = \left(\frac{M_{st} - M_{eq}}{M_{in} - M_{eq}}\right) \tag{2}$$

The above formula can also be modified to $MR = M_{st} / M_{in}$. The unit of MR is dimensionless. The drying rate (DR) of Turkey berry during dehydration was calculated using Eq. (3) [16,17]:

$$Drying\ Rate = \left(\frac{M_{s,t_1} - M_{s,t_2}}{t_1 - t_2}\right) \tag{3}$$

Determination of effective moisture diffusivity

Fick's second law of diffusion equation was used to investigate dehydration data and estimate the effective moisture diffusivity (D_{eff}):

$$\frac{\partial M}{\partial t} = D_{eff} \frac{\partial^2}{\partial t} \tag{4}$$

Assuming the sample is spherical and moisture movement occurs only by diffusion, the moisture ratio can be calculated using the formula of Eq.5. [11,17]:

$$MR = \frac{M_{st} - M_{eq}}{M_{in} - M_{eq}} = \frac{6}{\pi^2} \sum_{n=1}^{\infty} \frac{1}{n^2} \exp\left(\frac{-D_{eff} n^2 \pi^2 t}{R_p^{\,2}}\right) \tag{5}$$

For long drying times when the moisture ratio is greater than 0.6, the first term in their series of equations can be considered, and then the Eq. (5) can be rewritten as Eq. (6) [11,17]:

$$MR = \left(\frac{6}{\pi^2}\right) \exp\left(\frac{-D_{eff} \pi^2 t}{R_p^{\,2}}\right) \tag{6}$$

By taking natural logarithm on both sides, Eq. (6) can be linearized to Eq. (7):

$$\ln MR = \ln\left(\frac{M_{st}-M_{eq}}{M_{in}-M_{eq}}\right) = \ln\left(\frac{6}{\pi^2}\right) - \left(\frac{D_{eff}\pi^2 t}{R_p{}^2}\right) \quad (7)$$

The linear slope S_1 is determined by plotting ln*(MR)* against *t*:

$$S_1 = \left(\frac{D_{eff}\pi^2}{R_p{}^2}\right) \quad (8)$$

Volumetric shrinkage (S_p)

The sample volumes have been measured with the help of a digital Vernier caliper by three measurements of the young Turkey berry diameter in the respective coordinate axes. During the dehydration, three samples were measured for every test. The volume reduction was acquired as a ratio of the sample volume at any time of dehydration ($V_{s.,t}$) to the original volume of the fruit (V_{in}).

According to the following equation, as mentioned by Junquera *et al.* [18], a second-order polynomial equation is suitable for the relationship between variations in volume ratio to sample moisture content, as described in Eq. (9):

$$\frac{V_{s,t}}{V_{in}} = a_1 M_{s,t}{}^2 + b_1 M_{s,t} + c_1 \quad (9)$$

Color measurement

A tri-stimulus colorimeter (model 2810) was used to test the Turkey berry color under a D65 illuminated lamp at a 10° viewing angle, calibrated with the help of a white ceramic tile. Color values were represented as L- varying from lightness to darkness (100-0), "a" varying from redness to greenness (+ ve to - ve), and "b" varying from yellowness to blueness (+ ve to - ve), on the Hunter scale; the subscripts of 'fi' and 'in' denotes final and initial value. Three measurements were taken for each sample at three different places, and the average value was recorded. The following values of the total color difference (TCD or ΔE) and the Chroma differences (ΔC) were calculated from the values of "L", "a" and "b" [9,19].

$$\Delta E = \sqrt{(L_{fi}-L_{in})^2 + (a_{fi}-a_{in})^2 + (b_{fi}-b_{in})^2} \quad (10)$$

$$\Delta C = C_{fi} - C_{in} \quad (11)$$

$$C_{fi} = \sqrt{(a_{fi})^2 + (b_{fi})^2} \quad (12)$$

$$C_{in} = \sqrt{(a_{in})^2 + (b_{in})^2} \quad (13)$$

Ascorbic acid content (AA)

Ascorbic acid content was evaluated (AA or vitamin C) using 2,4-dinitrophenyl hydrazine [18], as described by the colorimetric procedure. AA was extricated with 0.5% oxalic acid, purified, and dosed up in the extract. Then, the absorbance was measured at 520 nm by a spectrophotometer using the standard AA; the measurements were repeated thrice, and their values were given in mg/100 g.

Microstructure analysis

The microstructure of dehydrated turkey berries was examined using a scanning electron microscope (VEGA3, TESCAN). To acquire SEM pictures, tiny fragments were collected from the fruit skin and covered with a fine layer of Nano-gold under a high vacuum to offer an illuminating surface for the electron beam. The gold coating was deposited on the sputter coater (SC-7620, Mini Sputter Coater) with argon gas as a medium at a pressure lower than the atmosphere.

Statistical evaluation of the quality analysis

Three batches were independently conducted for every drying test, and the data were mutually analyzed. Result analysis of one-way ANOVA was performed using the software IBM SPSS Statistics 22.0. To find statistical significance, different variables were compared using the Tukey test at a confidence level of 95% [20]. The results obtained were presented as mean values with a standard deviation.

RESULTS AND DISCUSSION

Drying curves

To examine the effect of different pretreatment methods on the drying kinetics of Turkey berry, the curves showing the variation of the moisture content with time were analyzed (Figure 2). The initial moisture content of 5.25 ± 0.05 (kg water/kg dry matter) was reduced to final moisture content. It was observed that a higher amount of water was removed from the pretreated samples than from the untreated ones.

The untreated samples were dried for 645 min. Similarly, the drying duration for the physically pretreated samples (T2 and T3) was from 495 mib to 530 min, while the chemically pretreated samples (T6, T7, T8, and T10) took 480 to 580 min. The drying times of the hybrid (T9) and combined physical (T4 and T5) pretreatments were 420 min and 330–400 min, respectively, thus being shorter by 38–49% and 34% than the untreated samples.

The combined physically pretreated samples (T5 and T4) dipped in hot water (blanching) with abrasive before the dehydration process had shorter drying times than the other samples. The T5 samples were initially blanched, followed by a friction process. As a result, the

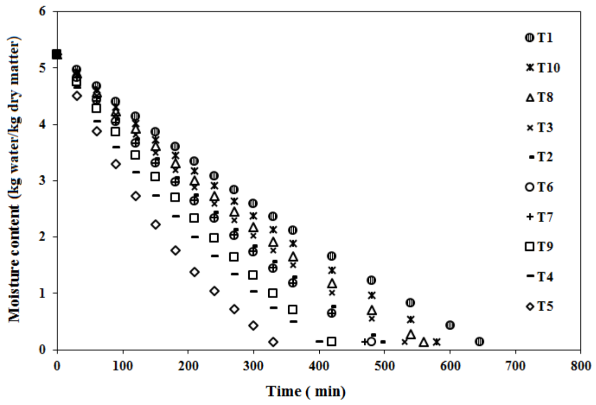

Figure 2. Evolution of moisture content of pretreated samples during drying at 70 °C and 4 m/s.

softened solid tissues were obtained, and the microscopic cracks on the fruits were effectively developed. At the same time, the T4 process created the micro-cracks initially, which might be partially closed by the effect of swelling due to the blanching action. Hence, the T5 process was approximately 17.5% shorter than the T4 one.

From the analysis of the drying curve and variability, it was found that the oil type in the T6 and T7 samples had an insignificant effect during the dehydration of fruit, and its drying time was observed as 430 and 435 min. The drying curve of the T7 sample showed that the drying rate was higher than that of the T8 sample while using a high concentration of Sesame oil. However, increasing the immersion period for the T8 sample, compared to the T10 sample, did not affect the dehydration process. Significant differences were observed for the T2, T4, T5, and T9 samples. Still, the curve shows no considerable difference when the T4 and T9 samples were compared during the dehydration process.

Figure 3 shows the time variations of the drying rate for the fruits. The maximum dehydration rate occurred for the fruit pretreatments in the following order: T5, T4, and T9, followed by the remaining processes. In addition, the drying rate of the samples from the combined physical and hybrid pretreatment was approximately 2.5 times and twice higher for the T5 and the T9 samples than for the untreated samples. A similar result was obtained as grapes dried in a convective dryer [5]. The experimental results confirm that the exposure of the samples to the physical and chemical pretreatment increases the drying rate positively.

The fruit's wax layer is exposed to high temperatures, converting the cellular structure of solids from anisotropic to isotropic, subsequently increasing the permeability of the peel surface. Similarly, chemical pretreatments of peanut or sesame oil with a salt solution alter the texture of the fruit's wax layer and reduce surface tension, resulting in improved water permeability of the samples. In addition, these "fatty acids" interrelate with soluble waxes and establish "hydrophilic" relationships between the fruit surface [9] and the water-rich cellular tissue (intra and inter cells). Similar results were observed in several products, such as red kidney bean seeds [2], grapes [5], cape gooseberries [9], and plums [11].

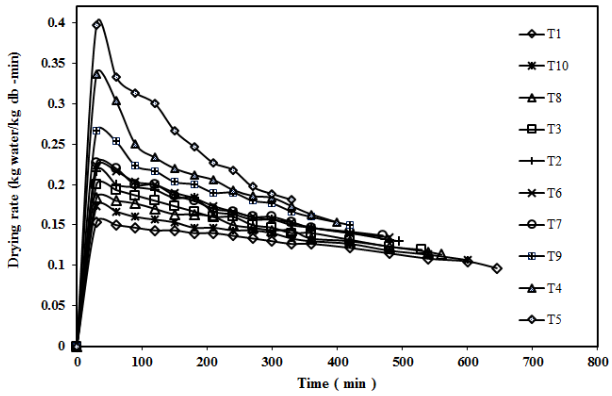

Figure 3. Drying rate (DR) of pretreated Turkey berries drying at 70 °C and 4 m/s.

Effective moisture diffusivity

The relation of ln(*MR*) with time for various pretreated and untreated samples can be seen in Figure 4. The D_{eff} values of the fruits computed using Eq.7, along with the coefficient of determination (R^2), are presented in Table 2.

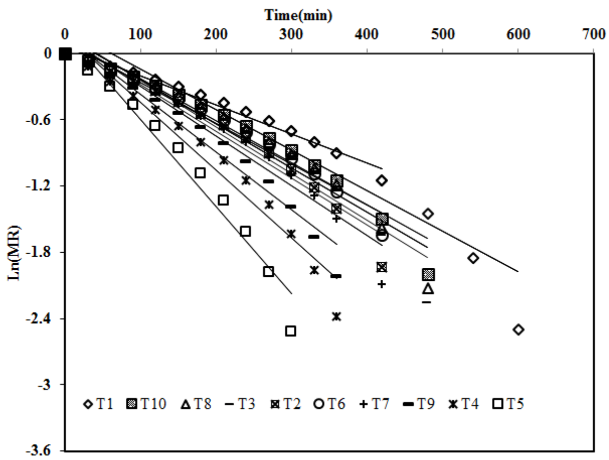

Figure 4. ln*(MR) vs. time for different pretreated samples during drying at 70 °C and 4 m/s.*

The D_{eff} values of the pretreated and untreated samples range from 2.928 × 10^{-10} m^2s^{-1} to 6.002 × 10^{-10} m^2s^{-1} and are within the range of 10^{-11} m^2s^{-1} to

Table 2. Variation of moisture diffusivity coefficients (D_{eff}) and volumetric shrinkage coefficients

Parameters		T1	T2	T3	T4	T5	T6	T7	T8	T9	T10
Shrinkage (S_P)	a	0.0012	-0.0032	-0.0049	-0.0078	-0.0076	-0.002	-0.0045	-0.0028	0.001	- 0.003
	b	0.0971	0.1011	0.1145	0.1075	0.1006	0.0969	0.0979	0.1157	0.066	0.1182
	c	0.4451	0.5552	0.5265	0.6495	0.6781	0.5585	0.6057	0.4694	0.6352	0.4509
	R^2	0.9979	0.9972	0.9934	0.9969	0.9946	0.9945	0.9934	0.9924	0.9962	0.9925
Effective moisture diffusivity (m^2 /s)	x10^{-10}	2.928	4.154	3.769	5.543	6.002	4.308	4.385	3.462	5.232	3.154
	R^2	0.924	0.959	0.941	0.959	0.962	0.951	0.959	0.945	0.958	0.952

10^{-8} m^2s^{-1} found for several agri-products [17]. For the untreated samples, the effective moisture diffusivity is 2.928×10^{-10} m^2s^{-1}. In the case of the physically pretreated samples (T2 and T3), the effective moisture diffusivity was 4.154×10^{-10} m^2s^{-1} and 3.769×10^{-10} m^2s^{-1}, respectively, whereas for the chemical pretreated samples (T6, T7, T8, and T10) range from 3.154×10^{-10} m^2s^{-1} to 4.385×10^{-10} m^2s^{-1}. The effective moisture diffusivity of the T9 sample is 5.232×10^{-10} m^2s^{-1}, while for the combined physically pretreated samples (T4 and T5), it is 5.543×10^{-10} m^2s^{-1} to 6.002×10^{-10} m^2s^{-1}. The D_{eff} value of the T5 sample increases drastically due to higher micropores and cracks, increasing the mass transfer efficiency during drying.

Similarly, for high-temperature physical, combined physical, and hybrid pretreatment methods, the action of "turgidity" reduces considerably and improves the porosity of sample tissues. Consequently, it enhances the sample's permeability [5]. Chemical pretreatments alter the peel structure of the fruit and minimize the surface tension effect on the cell wall. The above-mentioned causes for the pretreated samples positively enhance the effective moisture diffusivity by modifying the cell membrane structures. Effective moisture diffusivity is directly proportional to the drying rate [5,9].

Volumetric shrinkage

The volume ratio ($V_{s,t}/V_{in}$) was calculated to evaluate the volume reduction of turkey berries during dehydration while the volume of fresh fruit was 0.144 ± 0.002 x 10^{-5} m^3. The effect of the change in volume ratio against the reduction in moisture content is shown in Figure 5. When the samples reached the specified final moisture content, the highest volumetric shrinkage ratio of 0.68 and 0.66 was found in the T5 and T4 samples, respectively. In contrast, the lowest value of 0.46 was found for the T1 sample.

Typically, when samples are subjected to an extended dehydration process resulting injuries to the cell structure and induce significant shrinkage of the volume [18]. Figure 5 shows that chemical, combined physical, and hybrid pretreatments lead to a slight volume change and have an optimistic effect on maintaining the structure of the dried fruit. In this study, it was observed that the volumetric shrinkage was inversely proportional to the drying rate.

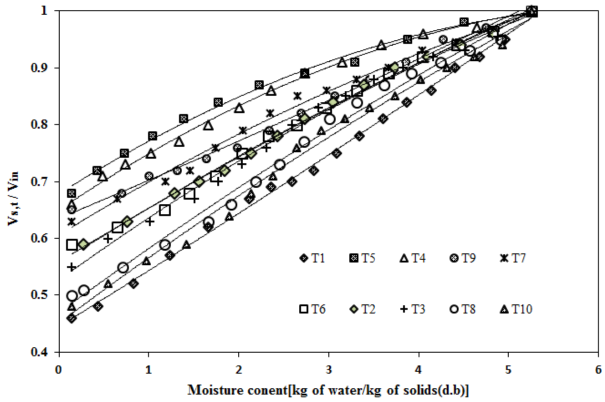

Figure 5. Volumetric shrinkage of different pretreated samples during drying at 70 °C and 4 m/s.

The second-order polynomial equation, Eq. (2), was adopted to correlate the moisture content and the volumetric ratio. Table 2 shows the R^2-values and the parameters of Eq. (2) for all pretreated and untreated samples. In addition, the higher values of R^2 (0.9) demonstrate that the equation is in excellent agreement with the experimental data [5].

Color

Color is one of the essential consistent proof of food quality in the food industry. To calculate the color change in fruit, Eqs.(10-13) were used. Table 3 shows the color variations of dried fruits, which are affected by the physical and chemical preparations, and the actual values of fresh and dehydrated turkey berries. Fresh fruit color values were measured as the lightness of 70.77, the greenness of-7.78, and the yellowness of 26.38, as shown in Table 3. The lightness values of untreated, physical, and combined physically pretreated samples were decreased to some extent, whereas in the chemically and hybrid pretreated samples were increased marginally. Table 3 shows that the final value of lightness (L_{fi}) varied from 62.28 to 66.18 for the physical and combined physical pretreated dried samples. In contrast, for the chemically and physicochemically pretreated samples, the values ranged from 72.86 to 75.23, while for the untreated sample, it was 60.46.

The final 'a_f'-value varied from -5.64 to -4.68 in the case of the physically and combined physically pretreated samples, whereas for the chemical and hybrid pretreated samples, it varied from 1.98 to -5.78; for the untreated samples, it was -4.28. Similarly, the final value of 'b_{fi}' varied from 17.46 to 19.22 for the physically and combined physically pretreated samples, whereas the chemically and physicochemically pretreated samples ranged from 19.81 to 29.16; for the untreated samples, it was 16.43 (Table 3).

The total color differences (TCD or ΔE) of the pretreated samples were found as significantly different ($\alpha < 0.05$) (Table 3). The TCD values of physical and combined physical treated dried samples varied from 8.55 to 12.7, whereas chemical and hybrid treated dried samples ranged from 7.18 to 10.88. The untreated sample value of 14.75 was observed from this study.

During the dehydration process, the untreated sample was dried prolonged time; consequently, the sample was strongly affected by the caramelization and enzymatic browning reactions. Generally, when the foodstuffs are exposed to high-temperature conditions, the oxidation of total phenolic acids and the chemical reactions of carbohydrates or amino acids occur in foodstuff. The degree of color change depended on the drying temperature, processing time, and oxygen level in the air used in the process [21].

Compared with the untreated sample, less degradation of color was observed in the abrasion-treated fruits (T3). In the HTST process, the least color damage occurs in thermal treatment, inhibiting the enzymatic browning due to the inactivation of polyphenol-oxidase (PPO) during the drying [20,22]. The degradation of skin color on the sample was observed in the HTST processes, as listed in the table in the following order: T4> T2 > T5 > T9.

Based on the experimental results, the lowest degree of darkening was found in all chemically pretreated samples (highest L-values). The edible oils, such as peanut and sesame oils, were used in the T6-T10 treatments to help to mitigate the changes in the color of the fruit due to the development of a defensive coating on the outer surface of the samples. Thus, the chemical and hybrid treated samples were preventive against oxidation and controlled the caramelization and enzymatic browning reactions during the dehydration process [9].

Chroma represents the degree of color; it has varied from low Chroma values (dull colors) to high Chroma values (bright colors). From Table 3, Chroma (ΔC) variations are negative for the pretreated and untreated samples except for the T7, T8, and T10 samples. This result indicates that the drying processes with the chemically pretreated samples were better than those with the physically pretreated ones. From Table 3, the difference in Chroma values confirms the color saturation shown in the photo images. The visuals of the fruits are sequenced as dark to bright color in Table 3 as in this progression: T1 < T4 < T3 < T5 < T2 < T9 < T6 and T8 < T10 < T7.

Ascorbic acid retention

Table 3 displays the content of ascorbic acid (vitamin C) in the dehydrated Turkey berries. The vitamin C content of fresh fruit is 3.81 ± 0.32 mg/100 g (d.b.). This is in line with the earlier reports showing that the vitamin C content in Turkey berries is 2.86 mg/100 g [1] and 4 mg/100 g [23]. The vitamin C losses of the untreated and treated samples were significantly different ($\alpha < 0.05$) as observed in the dehydration process (Table 3). Unavoidable losses of vitamin C occurred due to its thermo-sensitivity character during the drying at 70 °C. Even though HTST achieved a short drying time in the case of the pretreated samples of T4, T5, and T9, the vitamin C losses were inevitable because of its solubility in water and sensitivity to heat during the blanching. Based on the experimental results, 34-36% of vitamin C content was retained in the T4, T5, and T9 samples.

Significant variations in the average values of the vitamin C content of dried berries in different pretreatments were observed by the analysis of variance ($\alpha < 0.05$). Vitamin C retention was higher in the physically pretreated samples, like the abrasively treated T3 sample, and the combined physically treated T4 and T5 samples, than in the untreated sample. Both blanching and abrasion prevented the samples from the influence of O_2 during the period of dehydration and minimal changes in the skin with short drying [10]. The untreated dried sample showed a significant loss of 70% in vitamin C due to the prolonged drying time of 645 min.

Despite the different oil types, the maximum ascorbic acid retention of 41% and 39% was found in the T6 and T7 samples, respectively. The vitamin E contents of peanut and sesame oil are 398.6 mg/kg and 450 mg/kg, respectively [24-25]. Thus, Vitamin E from

Table 3. Colour and nutrition evaluation of Turkey Berry fruits dried after chemical and physical pretreatments

Parameters	Fresh	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10
L^*	$70.77^{bc}\pm1.36$	$60.46^{f}\pm1.06$	$65.60^{de}\pm1.86$	$62.28^{ef}\pm1.12$	$64.14^{ef}\pm1.42$	$66.18^{cd}\pm1.08$	$73.23^{abc}\pm1.08$	$75.23^{a}\pm2.36$	$74.72^{ab}\pm2.32$	$72.86^{abc}\pm1.96$	$74.63^{ab}\pm2.06$
a^*	$-7.78^{b}\pm1.24$	$-4.28^{b}\pm1.98$	$-5.64^{b}\pm2.44$	$-4.68^{b}\pm1.88$	$-5.28^{b}\pm2.02$	$-5.64^{b}\pm2.12$	$1.88^{a}\pm2.12$	$1.98^{a}\pm0.86$	$1.94^{a}\pm0.44$	$-5.78^{b}\pm2.22$	$1.98^{a}\pm1.02$
b^*	$26.38^{a}\pm1.24$	$16.43^{c}\pm1.14$	$19.22^{bc}\pm2.44$	$17.46^{c}\pm1.08$	$18.85^{bc}\pm1.36$	$19.12^{bc}\pm1.12$	$29.04^{a}\pm1.12$	$29.16^{a}\pm3.24$	$28.52^{a}\pm2.66$	$19.81^{bc}\pm3.04$	$28.42^{a}\pm2.86$
ΔE	-	$14.75^{a}\pm0.35$	$9.09^{cd}\pm1.08$	$12.70^{b}\pm0.33$	$10.34^{bc}\pm0.05$	$8.55^{cd}\pm0.30$	$10.32^{bc}\pm0.30$	$10.88^{bc}\pm0.31$	$10.70^{bc}\pm0.42$	$7.18^{d}\pm1.33$	$10.69^{bc}\pm0.03$
ΔC	-	$-10.53^{c}\pm0.15$	$-7.47^{c}\pm0.88$	$-9.43^{c}\pm0.20$	$-7.93^{c}\pm0.05$	$-7.57^{c}\pm0.20$	$1.60^{a}\pm0.20$	$0.73^{ab}\pm1.54$	$0.47^{ab}\pm1.94$	$-6.87^{c}\pm1.52$	$0.99^{a}\pm0.27$
mg/100g*	$3.81^{a}\pm0.02$	$1.14^{f}\pm0.02$	$0.95^{g}\pm0.05$	$1.16^{de}\pm0.02$	$1.26^{f}\pm0.04$	$1.33^{cde}\pm0.06$	$1.48^{bc}\pm0.05$	$1.42^{bc}\pm0.03$	$1.22^{ef}\pm0.02$	$0.97^{g}\pm0.06$	$1.14^{f}\pm0.04$
Picture											

*Ascorbic acid content , Means followed by the same letter are not significantly different using the Tukey test (alpha = 0.05).

peanut and sesame oils donates free radicals to vitamin C for regeneration during drying, where the antioxidants prevent one another and strengthen oxidation resistance.

The experimental results reveal that vitamin C retention depends on processing temperature, pretreatment option, and drying time. However, the processing temperature plays a significant role in preserving the vitamin C content.

Microstructure evaluation

Microstructure evaluation was done by Scanning Electron Microscopy (SEM) to study the effects of the chemical and physical pretreatment processes (T1, T5, T6, T7, and T9) that occurred at high drying rates compared to the untreated samples. The SEM images of the samples before and after drying are shown in Figure 6.

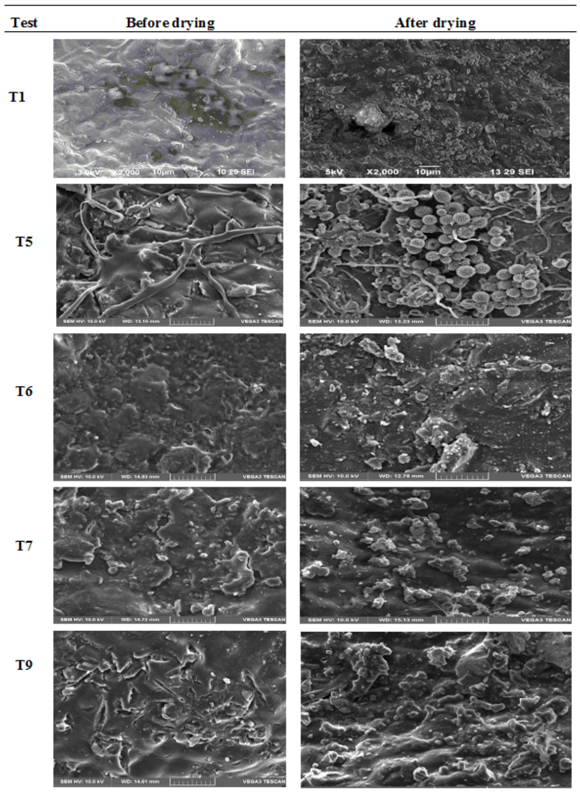

Figure 6. SEM images of fresh and dried Turkey berries.

Typical surface wax in fresh Turkey berry is shown in Figure 6. The better wax removal and the developed micro-cracks were observed in the combined physical pretreatment of T5 before drying. Formation of micro-pores and fully developed micro-cracks were visible after drying in the SEM image due to blanching with abrasion action. These micro-pores and micro-cracks support the shorter drying time of 330 min, shown in Figure 2. Microstructure evaluation images of the chemically pretreated samples T6 and T7 were similar. The images before drying show traces of wax on the surface, and micro-cracks are minimal compared to the T5 sample. After drying, the images of the T6 and T7 samples show fully developed micro-cracks and minimal micro pores compared to the T5 sample. The images of the T9 sample taken before and after drying show better micro-cracks and pores on the surface than the T6 and T7 samples. The primary structure of the cell membrane of the sample was disturbed because of the chemical and HTST actions [12,20].

SEM images show the effect of the chemical pretreatment in which micro-cracks were created in Turkey berry fruit peel by potassium carbonate and potassium hydroxide, with oil solution, resulting in a rapid drying rate. As well as in abrasion, treatment did not involve any loss of juice since not one big crack was observed either after the physical pretreatment or after drying in addition to the increased drying rate efficiently [5,9].

CONCLUSION

The effects of different pretreatments like an untreated, physical, chemical, combine and hybrid, on the drying kinetics and their qualities of Turkey berries were investigated using a fluidized bed dryer. Physical and chemical treatments have shortened drying times by reducing the samples' waxy skin obstinacy and enhanced heat and mass transfer.

Better wax removal and micro-cracks were produced in the combined physical and hybrid pretreatment methods followed by other pretreatment methods. Higher effective moisture diffusivity was obtained in the dehydration of Turkey berries when the fruits were exposed to combined physical and hybrid pretreatment. The combined physical pretreatment had the shortest drying time, the lowest shrinkage, acceptable retention of vitamin C, and color change were observed. In the HTST processing of the T9 sample, the loss of color was comparatively lower than that caused by the blanching and combined physical treatments. Increasing the time of immersing the chemically pretreated sample in the solution did not affect the drying process significantly. The chemical pretreatment with sesame oil of 9.5% and potassium carbonate of 4.75% was desirable to preserve the biochemical properties, like vitamin C retention. The processing temperature plays an important role in maintaining vitamin C content.

NOMENCLATURE

a_1, b_1, c_1	Quadratic equation constant, (dimensionless)
D_0	Preexponential factor of the Arrhenius equation, (m^2/s)
D_{eff}	Effective moisture diffusivity, (m^2/s)
DR	Drying rate a kg water/ kg dry matter x min
S_1	Slope of the line, (dimensionless)
M_s	Moisture content of the sample, (kg water / kg dry matter)
M_{in}	Initial moisture content of the sample, (kg water / kg dry matter)
M_{eq}	Equilibrium moisture content of the sample, (kg water/kg dry matter)
M_{st}	Moisture content at any time, (kg water/kg dry matter)
MR	Moisture ratio, (dimensionless)
n	Constant, positive integer of the equation
R_p	Radius of product, (m)
S_P	Shrinkage percentage of product, (dimensionless)
t, t_1, t_2	Time, (s)
V_{in}	Initial volume of sample, (m^3)
$V_{s,t}$	Volume of sample at any time, (m^3)
W_{st}	Sample weight at a specific time (g)
W_{dry}	Sample dry weight (g)
HTST	High temperature short time
K_2CO_3	Potassium carbonate
KOH	Potassium hydroxide
ΔE	Total color difference

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EFEKTI PRETHODNIH OBRADA NA SUŠENJE BOBICA GRAŠKA PATLIDŽANA (*SOLANUM TORVUM*) U SUŠARI SA FLUIDIZOVANIM SLOJEM

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NAUČNI RAD

Uticaj metoda prethodne obrade, kao što su fizički, hemijski, kombinovani fizički i hibridni postupci na bobice graška patlidžana (Solanum torvum) na poboljšanje difuzije vode tokom sušenja je procenjen zbog uklanjanja voštanog sloja na kori. Prethodno obrađeni i neobrađeni uzorci su sušeni na temperaturi od 70 ºC i protoku vazduha od 4 m/s u sušari sa fluidizovanim slojem. Bobice koje su prethodno tretirane kombinovano abrazijom i blanširanjem imaju najkraće vreme sušenja i dobro očuvanje sadržaja vitamina C od 36%. Najveće vrednosti brzine sušenja od 0,396 kg vode/kg min, maksimalne efektivne difuzivnosti vlage od 6,002 x 10^{-10} m^2/s i koeficijenta zapreminskog skupljanja od 0,68 imaju bobice tretirane kombinovanom fizičkom postupku. Maksimalne promene boje ΔE = 14,75 i Chroma ΔC = - 10,53 uočene su kod neobrađenih uzoraka.

Ključne reči: boja, efikasna difuzija vlage, prethodna obrada, skupljanje, bobice graška patlidžana.