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Research Article

Mathematical Modelling, Drying Behavior, and Quality Investigation of the Turkey Berry in a Fluidized Bed Dryer

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The dehydration behavior of turkey berries was analysed in a fluidized bed dryer at various inlet air velocities (0.8, 2.1, and 3.4 m/s) and temperatures (50, 60, and 70°C). The drying parameters and physiochemical values of fruits were extensively studied, as were the moisture content, rate of drying, moisture diffusivity of the sample, shrinking percentage, color variations, retention of vitamin C, β-carotene, antioxidant capacity, and total phenolic content. The activation energy varies between 36.82 and 45.63 kJ/mol under different bed conditions. According to the experimental results, it has been observed that the maximum moisture diffusion rate was 2.898×10^{-10} m^2/s and maximum retention rates of vitamin C, β-carotene, antioxidant capacity, and total phenolic content were 1.91 mg/100 g d.m, 184 μg/100 g d.m, 21.34 mg AAE/100 g d.m, and 513 mg GAE/100 g, during the drying of the sample at 70°C and 3.4 m/s. The minimum shrinkage (49.1%) and color variation ($\Delta E = 11.08$) were detected at 3.4 m/s and 70°C. The Midilli et al. model was fitted, which is the most preferable model for predicting the dehydration characteristics of turkey berries.

1. Introduction

Turkey berry, *Solanum torvum* (Solanaceae family), is a pharmaceutical plant that can be taken as a fresh or dried form. The vegetables are still used as traditional medicine by people in South India and other Asian countries, particularly in rural areas. This is an essential medicinal plant whose leaves, vegetables, and fruits are utilized as therapeutics for antihypertensive, viral fever, antioxidant, and antimicrobial purposes [1–3]. In addition, these fruits are also provided in addition to a regular diet. Nonetheless, they have a valuable supply of nutritious foods that will decay within a couple of days after harvesting, just like any other foodstuff. To prolong its lifespan, it must consequently be stored in a cold storage room or freezer or dried. Furthermore, dried foodstuffs are easier to move from one place to another and store in small places.

Dehydration of agro-food products in the open sun (OSD) is a simple and common process employed all around the world. However, there are other issues involved with drying in the OSD. The crop is harmed due to adverse weather conditions, agro-food product contamination from external elements, and degeneration caused by overheating

[4–6]. Furthermore, the drying rate is exceedingly low, which means that the drying period is substantially longer. As a result, the dehydration process must be practiced in a sustainable environment, as well as using a quick processing approach, in order to preserve its physical and biological qualities.

Many types of dryers were widely accessible in the food industry, including oven dryers, fluidized bed dryers, microwave dryers, drum dryers, freeze dryers, indirect solar dyers, and infrared radiation dryers. Among the different kinds of dehydration methods, fluidized bed dryers (FBDs) are employed all over the world for the dehydration of agro-food products [4, 7]. The FBD is known for its consistent dehydration as well as its effective heat and mass transfer phenomena, which effectively remove the moisture from foodstuffs within a short period of time. Furthermore, FBD is a convenient way to avoid overheating heat-sensitive fruits and vegetables [4, 8–13]. In addition, the FBD is the most popular type of dryer employed in various sectors, such as chemical industries, fertilizer industries, medicine industries, agricultural industries, and milk industries. In industries that handle particulates, FB dryers exhibit excellent evaporation rates. The advantages of FB dryers over traditional dryers include rapid drying with great product quality, minimal losses from nutrition, good air-stream interaction with the wet substances, significant heat transfer between the gas and wet substances, and suitable circulation rates. Several researchers have reported updated designs for FB dryers to improve the drying process while consuming the least amount of energy [9-15].

Numerous studies on the drying kinetics of various food products have been conducted, including Monukka seedless grapes [5], terebinth seeds [8], hawthorn fruit [14], soybean [15], and barberry [16]. Other key quality parameters of dried foodstuffs are shrinkage, color changes, vitamin C, β-carotene, antioxidant capacity, and total phenolic content; they also have a substantial impact on consumer acceptance and attractiveness. Shrinkage and color of several items such as soybean [15], hawthorn fruit [14], and terebinth seeds [8] as well as the physiochemical properties of several items such as blueberries [17], myrtle fruits [18], sea buckthorn fruits [19], and goji berries [20] have been reported in detail in the previous literature.

As per the review of extant literature, no research has been conducted on the mathematical modelling and minimum fluidization behavior of turkey berry in a FBD. With these considerations in mind, the current research was carried out to examine the dehydration parameters of the samples, like the minimum fluidization velocity, rate of drying, diffusivity of water molecules, amount of energy required for activation of water molecules, percentage of volumetric shrinkage, and overall color variation of the turkey berries at different bed conditions. In addition, other key bioactive properties like vitamin C, β-carotene, antioxidant capacity, and total phenolic content of turkey berries at different bed conditions were also studied. This research also revealed a befitting model for estimating the dehydration behavior of the turkey berry.

2. Materials and Methods

2.1. Sample Preparation. The fruits were procured from the vegetable market, and the damaged and immature samples were removed from the lot. Turkey berry samples of uniform size and unimpaired fruit were separated from the entire bunch of procurements, allowing for additional experimentation. The mean diameter of the samples was metered and recorded as 13.2 ± 0.8 mm, and one piece of the berry weight of 1.9 ± 0.3 g was utilized for the trials. According to the AOAC (1990) procedure [21], the initial water content of the sample was examined by employing 8 g of fresh fruit, and the mean value was found to be 5.22 ± 0.03 kg water/kg dry matter (dry basis). Before introducing the sample into the chamber, the sorted-out samples were chosen for the studies and held at 5 ± 1°C.

2.2. Experimental Setup. The dehydration behavior and physiochemical quality of the sample were investigated using a batch type fluidized bed dryer (FBD), as illustrated in Figure 1. The FBD's primary features include a backward-type centrifugal blower with VFD, a controllable electric heater, and an air filter.

The whole setup as well as the drying chamber is fabricated by S.S (stainless steel) having a height of 0.85 m and an interior diameter of 0.14 m. The air circulated all over the bed by way of the punctured S.S plate, which has a hole with a dimension of 3.8 ± 0.02 mm and a trilateral space of 7.8 ± 0.03 mm with only 21 ± 0.1% open area. A hot wire anemometer was used to monitor the input air flow with a precision of 0.2 m/s. An electric heater heats the air before it is flown to the drying chamber. A pressure measuring instrument was used to record the pressure difference during the experiment.

2.3. Analysis of Minimum Fluidization Velocity and Drying Procedure. During the dehydration of samples, the pressure drop (Δp) and the inlet air velocity were determined, and the peak "Δp" point was detected as point B, as shown in Figure 2. The existence of bed conditions is defined in point B, which is referred to as the "minimum fluidization point/semifluidized bed" [22]. Two conditions, such as "A" and "C," were selected randomly from the chart, in such a way that the velocity of A is smaller than B and the velocity of C is higher than B. In addition, points A (0.8 m/s) and C (3.4 m/s) refer to the fixed bed and fluidized bed conditions, and point B (2.1 m/s) is equal to the condition of a semifluid bed.

Drying studies were performed at three inlet temperatures of 50–70°C and three velocities (A, B, and C) as well as keeping the sample weight at 250 g. Initially, by adjusting the inlet temperature and flow velocity of air, the dryer attained a steady-state mode; thereafter, the sample was introduced into the drying cabin. Every half hour, the entire sample was emptied from the bed, and the weight was recorded using an electronic weighing scale with a precision of 0.01 g. Following the weight recording, the fruits were loaded into the drying chamber for an additional 30 minutes to further reduce their moisture content. The fruits were loaded till the

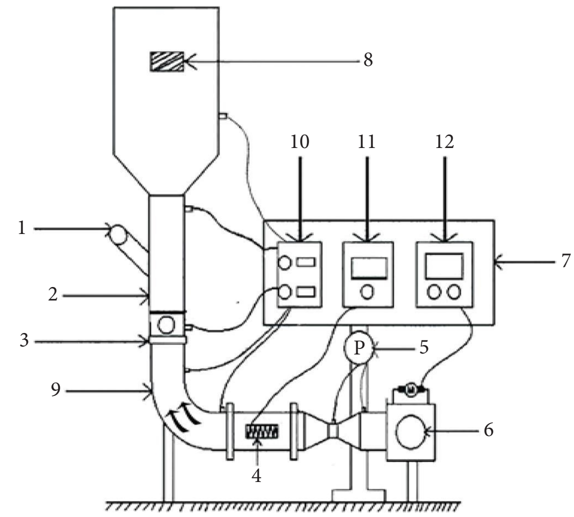

Figure 1: Schematic diagram of the fluidized bed dryer.

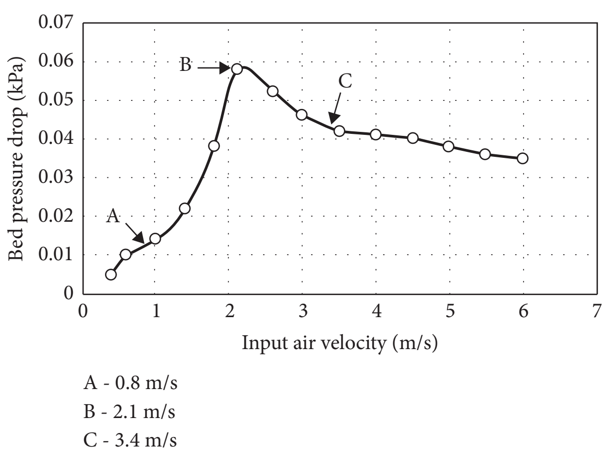

Figure 2: Fluidization curve of turkey berry.

moisture level was less than 0.14 ± 0.05 g water/kg dry matter (d.b). Three investigations were carried out for each experimental condition to establish the reproducibility of the analysis.

2.4. Drying Curves. The weight loss of a product as a function of time is used to evaluate drying parameters systematically. The water content of berries was calculated on a dry basis (d.b) by the following equation [4, 23]:

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

The moisture ratio (MR) of the berry during the dehydration process in a fluidized bed is determined by the following formula:

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

Equation (2) is changed in the form of $\text{MR} = M_{\text{st}}/M_{\text{in}}$, and the moisture ratio is a nondimensional unit. The experiment data were transformed into a moisture ratio and correlated to the different kinds of drying models reported in the literature which are described in Table 1. The various empirical drying models that were employed in this analysis were intended to find a reliable model for the drying performance of turkey berries. The drying rate (D.R) of the berry in the time of drying was estimated by the following equation [5]:

$$\text{D.R} = \left(\frac{M_{s,t_1} - M_{s,t_2}}{t_2 - t_1}\right). \quad (3)$$

2.5. Computation of Effective Moisture Diffusivity (D_{eff}). Fick's second law of diffusion equation was employed to examine drying kinetic parameter and predict D_{eff} of the materials with spherical geometry:

$$\frac{\partial M}{\partial t} = D_{\text{eff}} \frac{\partial^2}{\partial t}. \quad (4)$$

Considering that the sample of the turkey berry is almost spherical and the phenomenon of moisture migration occurs solely through diffusion, the MR can be determined by the following equation [5–8]:

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

During the dehydration periods where the moisture ratio seems to be beyond 0.6, the first part of their sequence of equations is evaluated, and equation (5) can thus be reformulated as

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

Using natural log on both left and right hand sides of equation (6), the first-degree equations such as linear equations are formed and rewritten as

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

By graphing the drying time against natural logarithmic of moisture ratio data of ln (MR), linear slope S_1 was obtained:

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

2.6. Determination of Activation Energy (E_{act}). The Arrhenius relationship is used to define E_{act} which communicates the interrelationship with D_{eff} and the supply air temperature (T_{in}) as shown in the following equation [5, 8–13]:

Table 1: Name of the different drying models.

Name of model	Model equation
Newton	$MR = Exp(-k_1 t)$
Page	$MR = Exp(-k_1 t^m)$
Henderson and Pabis	$MR = a_1 Exp(-k_1 t)$
Logarithmic	$MR = a_1 Exp(-k_1 t) + b_1$
Midilli et al.	$MR = a_1 Exp(-k_1 t^m) + b_1 t$
Logistic	$MR = a_1/(1 + b_1 Exp(k_1 t))$

a_1, b_1, k_1, and m are mathematical model coefficients.

$$D_{eff} = D_c \exp\left(-\frac{E_{act}}{R_{Ug}T_{in}}\right). \quad (9)$$

Using natural log on both left and right hand sides of equation (9), the upcoming findings are derived:

$$\ln(D_{eff}) = \ln(D_c) - \left(\frac{E_{act}}{R_{Ug}T_{in}}\right). \quad (10)$$

By graphing the inverse inlet temperature of air ($1/T_{in}$) against natural logarithmic of moisture diffusivity values of Ln(D_{eff}), linear slope S_2 was obtained:

$$S_2 = \frac{E_{act}}{R_{Ug}}. \quad (11)$$

2.7. Analysis of the Quality

2.7.1. Computation of the Volumetric Shrinkage (VS_p). The berry dimensions were determined using a digitized Vernier caliper to compute their initial volume. Furthermore, the sample was measured multiple times along the relevant axis. After dehydration of the sample, select any three samples from each test and measure their dimensions. With the help of equation (12), the change in volume percentage was calculated as a ratio of the volume of dehydrated berries (V_{fi}) to the volume of raw berries (V_{in}) [8, 14].

$$VS_p = \left(\frac{V_{in} - V_{fi}}{V_{in}}\right) \times 100. \quad (12)$$

2.7.2. Computation of Total Color Change. A tristimulus colorimeter (Model: VT-10) was measured to assess the skin color of turkey berries under a D65 light lamp at a 10° camera angle. On the Hunter scale, color values were expressed as L—ranging from brightness to darkness (100–0), "a"—ranging from redness to greenness (positive to negative), and "b"—ranging from yellowish color to blueness (positive to negative), with the subscripts "fi" and "in" denoting final and initial intensity of color. For every sample, three data points were measured in three distinct locations, and the mean reading was calculated. Total color difference (ΔE) values were determined from the variables "L," "a," and "b" [13, 23, 24]:

$$\Delta E = \sqrt{(L_{fi} - L_{in})^2 + (a_{fi} - a_{in})^2 + (b_{fi} - b_{in})^2}. \quad (13)$$

2.7.3. Determination of Vitamin C and β-Carotene. According to AOAC No. 967.21 [25], vitamin C, also known as ascorbic acid (AA), was identified using the analytical discoloration of 2,6-dichlorophenolindophenol. In order to compare the amounts of vitamin C in fresh and dried turkey berries, 5.0 ± 0.1 g of each sample was crushed and diluted in 1 L of distilled water. The amount of vitamin C was given as mg AA/100 g d.m. Similarly, β-carotene content was determined with the help of the spectrophotometric method, modified from López et al. [26]. Hexane, acetonitrile, and ethanol were used to extract the β-carotene, which was then measured at wavelengths of 503 nm and 480 nm, respectively. Each test was made three times.

2.7.4. Determination of Total Phenolic Content and Antioxidant Activity. According to Chen et al. [27], the Folin–Ciocalteu method was modified to estimate the extract's total phenolic content (TPC). Two 0.5 mL aliquots of the turkey berry extract solution, made with 100% ethanol, were thoroughly combined in a vortex with 0.5 mL of the Folin–Ciocalteu reagent and 2 mL of 20% Na_2CO_3 solution. After 15 minutes of incubation at room temperature, 10 mL of ultra-pure water was added, and the layer of precipitate that had developed was removed by spinning for 5 minutes at 4,000 × *g*. At 725 nm, the absorbance was detected in a spectrophotometer to be compared to a curve that was calibrated for gallic acid equivalent (GAE). The findings were expressed as mg GAE per 100 g of d.m. Three measurements were taken for each test.

The phosphomolybdenum technique was used to assess the turkey berries' overall antioxidant capability [28]. 1 mL of the reagent solution (0.6 M sulfuric acid, 28 mM sodium phosphate, and 4 mM ammonium molybdate) was added to 2 mL of the extract. Each of the tubes was sealed and heated to 50°C (boiling water bath) for 90 minutes. Using a spectrophotometer, the absorbing capacity of all the solutions was detected at 695 nm against a blank of the reagent after the samples had cooled to ambient temperature. The findings were expressed as ascorbic acid equivalent (AAE) in AAE mg per gram d.m. Three measurements were taken for each test.

2.8. Statistical Evaluation of the Equations. The six mathematical models are listed in Table 1, and these models were applied to turkey berry drying data (MR vs. time). MATLAB software (MathWorks Inc.) was employed to build mathematical models for MR of the product.

Three indicators, namely, sum of squared errors, root mean square error, and square of coefficient of correlation (R^2), were applied for choosing the appropriate model to symbolize the dehydration behavior of the sample and their equations as described in equations (14)–(16) [7, 15, 23, 27–29]. A suitable model can be chosen on the basis of the indicator value such as the maximum values of R^2 as well as the minimum values of SSE and RMSE observed from the analysis results.

$$\mathrm{SSE} = \sum_{j=1}^{M} \frac{\left(\mathrm{MR}_{\mathrm{test},j} - \mathrm{MR}_{\mathrm{pre},j}\right)^2}{M-n}, \quad (14)$$

$$R^2 = \frac{\sum_{j=1}^{M}\left(\mathrm{MR}_{\mathrm{test},j} - \mathrm{MR}_{\mathrm{test}}\right)\left(\mathrm{MR}_{\mathrm{pre},j} - \mathrm{MR}_{\mathrm{pre}}\right)}{\left[\sum_{j=1}^{M}\left(\mathrm{MR}_{\mathrm{test},j} - \mathrm{MR}_{\mathrm{test}}\right)^2 \sum_{j=1}^{M}\left(\mathrm{MR}_{\mathrm{pre},j} - \mathrm{MR}_{\mathrm{pre}}\right)^2\right]^{1/2}}, \quad (15)$$

$$\mathrm{RMSE} = \left[\frac{1}{M}\sum_{j=1}^{M}\left(\mathrm{MR}_{\mathrm{test},j} - \mathrm{MR}_{\mathrm{pre},j}\right)^2\right]^{1/2}, \quad (16)$$

where $\mathrm{MR}_{\mathrm{test},j}$ is the experimental moisture ratio of j^{th} data point, $\mathrm{MR}_{\mathrm{pre},j}$ is the predicted moisture ratio of j^{th} data point, M is the total number of occurrences, and n is the number of constants in the model equation.

2.9. Statistical Evaluation of the Quality Analysis. At each experimental condition, three trials were conducted, and the mean values were evaluated. A one-way ANOVA test was performed at 95% probability level using SPSS Statistics 29.0 (IBM Co., New York, USA). In the case of significant differences between subgroups, the post hoc Tukey test was used as a statistical test ($P < 0.05$).

2.10. Microstructure Analysis. A scanning electron microscope was employed to analyse the morphology of dried turkey berries (FEI Quanta 200 F SEM, Netherlands). To get SEM micrographs, miniscule pieces of fruit skin were collected and coated with a thin layer of nano-gold under a vacuum environment to provide an illumination surface for the electron gun. Gold coat was done with an argon gas, at a pressure smaller than the ambient pressure on a sputter coater (HV-DSR1 Sputter Coater).

3. Results and Discussion

3.1. Drying Curves. As shown in Figure 3, the rate of dehydration of fruits with respect to time was reduced steadily during the dehydration of the samples. According to the investigational findings, the declining rate of drying was discovered throughout for all circumstances, as well as the fact that the water transport from the inner core of the sample to the outermost peel is predominantly regulated by the diffusivity phenomenon. Also, a large amount of evaporation of moisture was recorded in the early stages of drying of berries, but the final stage had a lower rate. The highest and lowest drying rates are 9.4 gram of water at 70°C and 8.6 gram of water at 50°C, respectively, with fluidized bed velocity of 3.4 m/s, during the initial stage (1 hour), whereas at fixed bed conditions (0.8 m/s), these values were detected as 6.4 gram of water at 70°C and 5.4 gram of water at 50°C.

According to Figure 3, a substantial drying rate was recorded at higher inlet air temperatures with fluidized bed velocity. At the same time, the maximum drying rate was detected at 70°C irrespective of all inlet air velocities [4]. During the dehydration at high temperatures, the vapor pressure vigorously developed on the cell walls of the inside fruit structures, so a considerable amount of the turgor pressure of the fruit structure was reduced.

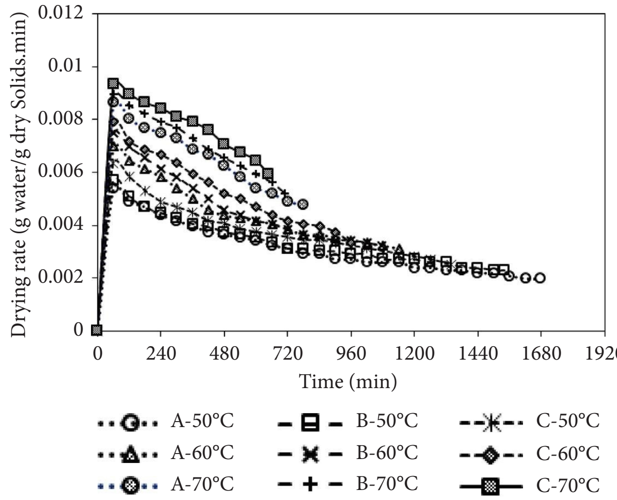

Figure 3: Drying rate with respect to time under various drying input parameters.

As a result of the preceding, the porous structure of the sample increases dramatically and has the proclivity to generate additional micropores and facilitate water movement from the center to the surface of the fruit [5]. At 70°C, cracks and micropores can appear, as can be seen in Figure 4(h). While there is no substantial effect on cell structure at a low temperature of 50°C, pore formation is inhibited, as seen in Figure 4(e). This is owing to the fruits' low water permeability, as shown in Figure 3.

Furthermore, at elevated temperatures and velocity, the phenomenon of heat and mass transfer processes is faster, contributing to rapid drying, thereby reducing the dehydration duration [8, 30, 31]. As a result of the experiment, at 70°C and fluidized bed condition, the rate of convective heat and mass transfer was superior to other conditions, resulting in a rapid drying rate and a shorter dehydration period. Figure 5 depicts the variation of the moisture level of the sample at various input parameters, and every line represents the amount of duration required to reduce the water potential from a beginning moisture content of 5.22 (d.b) to a final value of 0.14 (d.b).

It is demonstrated that the water level of the fruits progressively diminished with regard to time in all experiments, and that the dehydration period is significantly shorter in a fluidized velocity condition, irrespective of inlet air temperature, as shown in Figure 5. The dehydration duration of samples at temperatures of 50, 60, and 70°C was recorded as 1340, 960, and 645 min, respectively, at a superficial velocity of 3.4 m/s, as displayed in Figure 5. The drying period is shortened in terms of 2-fold times, once the temperature of incoming air rises from 50°C to 70°C; conversely, only around 20% was reduced when the inlet air velocities rise from 0.8 to 3.4 m/s. The drying of turkey berries was influenced more by the temperature of the incoming hot air than by its velocity [4, 11].

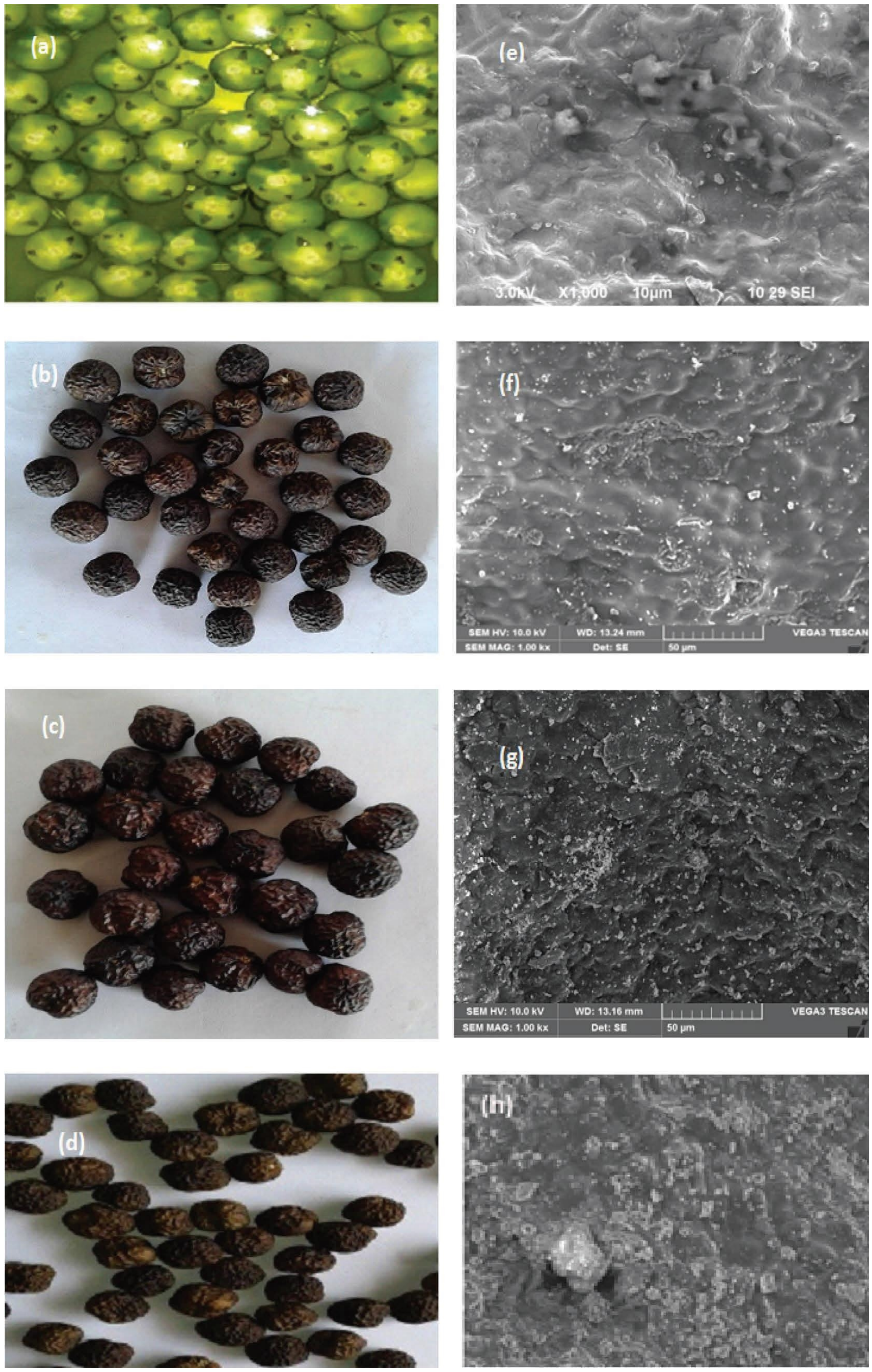

Figure 4: Photo view (a–d) and SEM picture (e–h) of fresh and dried samples at fluidized velocity.

3.2. Estimation of the Mathematical Models. In order to recognize an appropriate model that forecasts the drying kinetics of the fruits with the assistance of existing drying models, described in Table 1, the statistical information, including the estimations of R^2, RMSE, and SSE of various models utilized, is presented in Table 2.

The most appropriate drying model to address the dehydration behavior of the turkey berry was detected as the Midilli et al. [29] model, on the basis of the criteria of highest value of R^2 and lowest values of RMSE and SSE. As the estimated values of R^2 vary from 0.9992 to 0.9997, the RMSE values vary from 0.00006 to 0.00025, and the SSE values

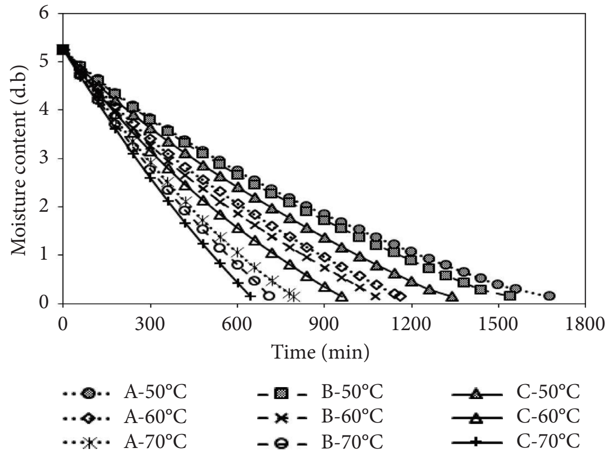

Figure 5: Moisture content of the sample with respect to time under various drying input parameters.

Table 2: Numerical values of various drying models at different input parameters.

Model name	T (°C)	R^2			SSE			RMSE		
		0.8 m/s	2.1 m/s	3.4 m/s	0.8 m/s	2.1 m/s	3.4 m/s	0.8 m/s	2.1 m/s	3.4 m/s
	50	0.9642	0.9646	0.9598	0.0539	0.0580	0.0608	0.0572	0.0566	0.0596
Newton	60	0.9614	0.9662	0.9714	0.0515	0.0436	0.0316	0.0585	0.0528	0.0512
	70	0.9538	0.9569	0.9482	0.0493	0.0429	0.0486	0.0669	0.0655	0.0734
	50	0.9938	0.9926	0.9865	0.0133	0.0119	0.0205	0.0244	0.0265	0.0204
Page	60	0.9881	0.9907	0.9886	0.0162	0.0122	0.0125	0.0336	0.0304	0.0125
	70	0.9878	0.9885	0.9879	0.0164	0.0115	0.0195	0.0364	0.0357	0.0194
	50	0.9732	0.9729	0.9659	0.0415	0.0452	0.0519	0.0515	0.0518	0.0571
Henderson and Pabis	60	0.9681	0.9724	0.9755	0.0433	0.0356	0.0274	0.0557	0.0524	0.0498
	70	0.9619	0.9644	0.9568	0.0645	0.0362	0.0413	0.0645	0.0635	0.0719
	50	0.9991	0.9993	0.9987	0.0004	0.0003	0.0016	0.0053	0.0039	0.0102
Logarithmic	60	0.9992	0.9994	0.9985	0.0004	0.0003	0.0017	0.0056	0.0048	0.0122
	70	0.9994	0.9993	0.9992	0.0002	0.0002	0.0009	0.0037	0.0046	0.0034
	50	0.9994	0.9992	0.9992	0.00008	0.00018	0.00014	0.0034	0.0035	0.0096
Midilli et al.	60	0.9995	0.9994	0.9994	0.00006	0.00013	0.00025	0.0022	0.0035	0.0092
	70	0.9996	0.9995	0.9997	0.00006	0.00006	0.00006	0.0012	0.0029	0.0033
	50	0.9967	0.9959	0.9923	0.0094	0.0067	0.0117	0.0181	0.0203	0.0275
Logistic	60	0.9924	0.9938	0.9914	0.0103	0.0081	0.0096	0.0282	0.0257	0.0308
	70	0.9905	0.9922	0.9921	0.0082	0.0079	0.0076	0.0305	0.0313	0.0327

range from 0.0012 to 0.0096, as presented in Table 2, and the evaluated values of the coefficients of the Midilli et al. model are shown in Table 3.

3.3. Effective Moisture Diffusivity. Figure 6 depicts the variation of Ln (MR) with function of drying time at various input parameters. The fruit's D_{eff} values were calculated using equation (7), and its R squared (R^2) was estimated using the linear equation, as listed in Table 4. The D_{eff} values exhibited a range between 8.792×10^{-11} and $2.898 \times 10^{-10}\ m^2 s^{-1}$ across various drying conditions. It is noteworthy that the D_{eff} values for turkey berries falls within the established range of 10^{-8}–$10^{-11}\ m^2/s$, consistent with the D_{eff} values reported for a majority of food commodities, as documented by Xiao et al. [5]. In the course of dehydration, the D_{eff} values were increased due to better convective heat and mass transfer phenomena occurring at 70°C and superficial velocity (3.4 m/s) circumstances. Table 4 demonstrates that the D_{eff} values varied from 8.792×10^{-11} to $1.305 \times 10^{-10}\ m^2/s$ at 50°C, 1.535×10^{-10} to $1.918 \times 10^{-10}\ m^2/s$ at 60°C, and 2.382×10^{-10} to $2.898 \times 10^{-10}\ m^2/s$ at 70°C during the dehydration when the inlet air velocities varied from 0.8 to 3.4 m/s. The preceding data suggest that both input air velocity and temperature influenced moisture diffusivity favorably; moreover, the D_{eff} values were influenced greatly by the temperature rather than air velocity [7–14, 30, 31].

Elevating the processing air temperature serves to increase the vapor pressure within the cellular structure of the fruit, primarily the cell wall. Consequently, this leads to a significant alteration in the turgidity pressure of the cell wall and subsequently enhances the porosity of the sample tissues. These adjustments collectively contribute to a notable improvement in the permeability of the material, as observed in the previous research [14].

Table 3: Midilli et al. model values under various input conditions.

Inlet velocity (m/s)	Model coefficients	Drying temperature (°C)		
		@ 50	@ 60	@ 70
0.8	a_1	0.9949	1.0018	0.9998
	b_1	−0.0001	−0.0003	−0.00068
	k1	0.0006	0.0018	0.00172
	m	1.1221	0.8729	0.9119
2.1	a_1	0.9970	1.0011	1.0013
	b_1	−0.0002	−0.00012	−0.00068
	k1	0.00068	0.0015	0.0018
	m	1.0728	0.9599	0.9341
3.4	a_1	0.9979	1.0053	0.9989
	b_1	−0.00038	−0.00038	−0.00092
	k1	0.0021	0.0029	0.0017
	m	0.8831	0.8615	0.9662

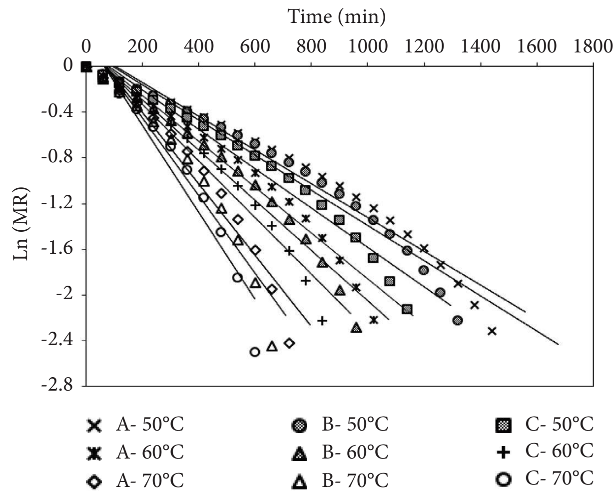

Figure 6: Ln (MR) with respect to time under various drying input parameters.

Table 4: Effective moisture diffusivity and activation energy values under various drying conditions.

Drying conditions	T_{in} (°C)	Input parameters				
		D_{eff}		Arrhenius equation		
		(m^2/s)	R^2	D_0 (m^2/s)	E_a (kJ/mol)	R^2
0.8 m/s	50	8.792×10^{-11}	0.9658	2.144×10^{-3}	45.63	0.9988
	60	1.535×10^{-10}	0.9666			
	70	2.382×10^{-10}	0.9465			
2.1 m/s	50	1.153×10^{-10}	0.9646	1.441×10^{-4}	37.73	0.9962
	60	1.689×10^{-10}	0.9665			
	70	2.612×10^{-10}	0.9359			
3.4 m/s	50	1.305×10^{-10}	0.9648	1.384×10^{-4}	36.82	0.9987
	60	1.918×10^{-10}	0.9639			
	70	2.898×10^{-10}	0.9249			

Based on the inference, the water migration from inner portion of fruit to outer surface remarkably increases and rapid convective mass transfer occurs rapidly using high air velocity flow over the samples.

3.4. Activation Energy (E_{act}). The energy needed to migrate the water molecules from the inner core of the foodstuff to outer peel and evaporate it is referred to as activation energy. Figure 7 depicts the Ln (D_{eff}) associated with the reciprocal of inlet air temperature ($1/T_{in}$) under various bed arrangements. E_{act} was evaluated through equation (9), and the coefficients of determination (R^2) for various inlet factors are shown in Table 4.

Average E_a values for various inlet parameters were discovered to be 36.82 to 45.63 kJ/mol in the experimental investigation of turkey berries dried in FBD. The value of E_{act} varies from 12.7 to 140 kJ/mol for various agro-foodstuffs

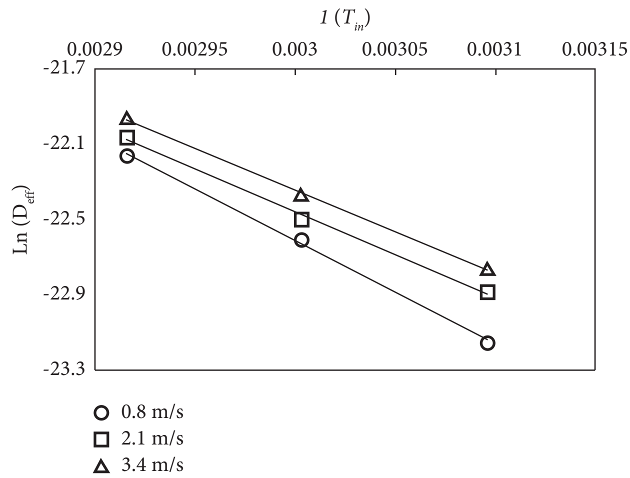

Figure 7: Ln (D_{eff}) vs. ($1/T_{\text{in}}$) under various drying conditions.

[16], which is consistent with the findings. Once the fruit was dried at fluidized bed condition, the E_{act} values decreased. As a result of the promising effect of heat and mass transfer by convection, the energy required to activate water molecules was reduced. Higher heat and mass transfer activity increases the dehydration rate as well as the diffusivity (D_{eff}) of the water molecules from inner core of the berry to the outermost peel layer of the sample. Table 4 shows that the minimum and maximum values of E_{act} are 3.4 m/s and 0.8 m/s, and Khanali et al. [13] and Taheri-Garavand and Meda [28] also showed the same tendency.

3.5. Quality Analysis

3.5.1. Volumetric Shrinkage. Table 5 shows the percentage of volumetric shrinkage at various bed conditions in FBD, and the change in dimensions of the berries was calculated by equation (13). The experimental results undoubtedly show that temperature and velocity have a substantial effect on the sample shrinking. Moreover, Table 5 shows that at fluidized bed conditions (70°C and 3.4 m/s), the volumetric shrinkage was 49.1 ± 1.1%, while at fixed bed condition (50°C and 0.8 m/s), it was 71.1 ± 0.9%.

ANOVA carried out for the volumetric shrinkage of turkey berries showed significant differences ($P < 0.05$) between the shrinkage percentages of various bed conditions of the dried samples, as presented in Table 5. The significant averages of samples dried at various temperatures (50 to 70°C) were also determined using a multiple comparison test, and it was shown that there were significant changes ($P < 0.05$) when the bed conditions changed from fixed to fluidized (0.8–3.5 m/s).

According to Figures 4(b)–4(d), the berries dehydrated at 50°C had a significantly greater effect on its original shape (greater shrinkage) than the products dehydrated at 60°C and 70°C. So, the water gradient between both the inside and external surfaces of the berry is minimal, and the removal of moisture evaporation was reduced during the low temperature involved in the drying, resulting in less internal stress developing on the cell wall. Furthermore, at relatively low temperatures, dried fruit was subjected to warm heat for a long duration, causing the cell walls of the tissues to be distorted. The largest dimension variations were noticed once the samples were dried at a low flow rate of air entering and a low inlet air temperature due to minimal permeability, smaller moisture differences on the inner and outer surfaces, and minimal vapor tension development on the cell structure [14, 32]. As a result, it is possible to deduce that the processing temperature has a substantial impact on the shape/volume of the fruits. According to Hatamipour and Mowla [32], reduction in volume/shape of the product is negatively related to the evaporation rate of moisture.

3.5.2. Total Color Difference (TCD). In the food sector, color is one of the most important quality indicators of food attributes, and color degradation is undesirable. Temperature and velocity had more influence on the change of color of the product, as seen in Table 5, and equation (14) was used to compute the total color change of the products. The brightness (L_i) of 71.2, greenness (a_i) of −7.83, and yellowish color (b_i) of 25.96 were used to calculate the fresh fruit color values in this investigation. The total color difference (TCD or ΔE) between dehydrated samples was determined to be substantively different as indicated in Table 5. At different bed conditions, the estimated TCD scores for dehydrated samples ranged from 11.08 to 21.12. ANOVA carried out for the volumetric shrinkage of turkey berries showed significant differences ($P < 0.05$) between the TCD values of various bed conditions of the dried samples, as presented in Table 5. The significant averages of samples dried at various temperatures (50 to 70°C) were also determined using a multiple comparison test, and it was shown that there were significant changes ($P < 0.05$) when the bed conditions changed from fixed to fluidized (0.8–3.5 m/s).

Table 5 shows that both parameters like brightness and yellowish color were dramatically lowered, resulting in a greater change in darkness as well as decreased greenness. Figures 4(a)–4(d) depict the influence of changing the surface color of the products as they dehydrate in FBD. When low inlet air velocity and low temperature were

Table 5: Variation of shrinkage and total color change of the turkey berry under various drying input parameters.

V (m/s)	T_{in} (°C)	Shrinkage (%)	Total color variations (ΔE)			
			L_{fi}	a_{fi}	b_{fi}	ΔE
0.8	50	71.2 ± 0.9^{a}	53.42 ± 0.8^{c}	-2.98 ± 0.12^{a}	15.34 ± 0.12^{c}	21.12 ± 0.14^{a}
	60	65.9 ± 1.2^{bc}	58.86 ± 0.6^{b}	-3.73 ± 0.07^{b}	15.31 ± 0.17^{c}	16.76 ± 0.22^{c}
	70	59.6 ± 1.4^{e}	64.12 ± 1.2^{a}	-5.22 ± 0.08^{c}	17.16 ± 0.14^{a}	11.65 ± 0.15^{e}
2.1	50	68.3 ± 1.6^{b}	53.5 ± 0.8^{c}	-3.12 ± 0.06^{a}	15.72 ± 0.28^{bc}	20.81 ± 0.11^{ab}
	60	60.7 ± 1.3^{de}	59.08 ± 0.6^{b}	-3.94 ± 0.04^{b}	15.93 ± 0.17^{b}	16.14 ± 0.16^{d}
	70	54.6 ± 1.8^{f}	64.28 ± 0.4^{a}	-5.28 ± 0.10^{c}	17.54 ± 0.16^{a}	11.25 ± 0.15^{fe}
3.4	50	63.9 ± 1.3^{cd}	53.82 ± 1.0^{c}	-3.26 ± 0.12^{a}	15.98 ± 0.12^{b}	20.39 ± 0.11^{b}
	60	55.8 ± 1.4^{f}	59.16 ± 0.6^{b}	-3.98 ± 0.08^{b}	16.11 ± 0.19^{b}	15.96 ± 0.14^{d}
	70	49.1 ± 1.1^{g}	64.37 ± 0.2^{a}	-5.31 ± 0.05^{c}	17.61 ± 0.15^{a}	11.08 ± 0.12^{f}

Different letters in same column indicate a significant statistical difference ($P < 0.05$).

Table 6: Variation of vitamin C content, antioxidant capacity, and total phenolic content of the turkey berries under various drying input parameters.

V (m/s)	T_{in} (°C)	Vitamin C content (mg/100 g d.m)	β-Carotene content (μg/100 g d.m)	Total phenolic content (mg GAE/100 g)	Total antioxidant capacity (mg AAE/100 g d.m)
Fresh	—	3.81 ± 0.44^{a}	400 ± 4.56^{a}	676.18 ± 8.38^{a}	53.42 ± 0.21^{a}
0.8	50	0.80 ± 0.01^{h}	100 ± 1.24^{i}	422.61 ± 9.12^{h}	11.75 ± 0.35^{h}
	60	1.07 ± 0.02^{g}	124 ± 1.56^{g}	453.04 ± 8.12^{efg}	14.96 ± 0.16^{f}
	70	1.37 ± 0.04^{e}	168 ± 1.56^{d}	486.85 ± 5.28^{cd}	18.68 ± 0.12^{d}
2.1	50	1.22 ± 0.05^{f}	108 ± 1.72^{h}	436.14 ± 7.24^{gh}	13.33 ± 0.21^{g}
	60	1.45 ± 0.02^{de}	132 ± 1.78^{f}	466.56 ± 8.15^{ef}	16.53 ± 0.17^{e}
	70	1.75 ± 0.04^{c}	176 ± 1.56^{c}	500.37 ± 5.17^{bc}	19.77 ± 0.33^{c}
3.4	50	1.49 ± 0.03^{d}	120 ± 2.15^{g}	446.28 ± 6.56^{fg}	14.93 ± 0.31^{f}
	60	1.68 ± 0.04^{c}	144 ± 1.98^{e}	473.33 ± 4.36^{de}	18.17 ± 0.23^{d}
	70	1.91 ± 0.01^{b}	184 ± 1.56^{b}	513.90 ± 8.38^{b}	21.34 ± 0.16^{b}

Different letters in same column indicate a significant statistical difference ($P < 0.05$).

involved in the dehydration of the sample by this means, it took drying for longer periods of time; consequently, it was strongly affected by both caramelization and enzymatic browning reactions [23]. Commonly, when the foodstuffs are subjected to high-temperature settings, total phenolic acids are oxidised, and carbohydrates or amino acids undergo chemical reactions. The amount of color deviation was affected by drying air temperature and processing duration, as well as the amount of oxygen present in flow of inlet air [13, 23, 24].

3.5.3. Retention of Vitamin C and β-Carotene. The vitamin C content of the dried turkey berries is shown in Table 6. Fresh fruit has 3.81 ± 0.44 mg/100 g d.m. This is consistent with past studies demonstrating that turkey berries contain 2.86 mg/100 g d.m [1] and 4 mg/100 g d.m [2], respectively. The analysis of variance revealed significant differences ($P < 0.05$) in the mean values of the vitamin C content of dried berries under various bed conditions, which are displayed in Table 6. In all nine studies, vitamin C retention was best when the sample was dried at an air temperature of 70°C and an air velocity of 3.4 m/s. The dried samples demonstrated a considerable loss of 79% in vitamin C at low intake air temperature and low inlet air velocity (0.8 m/s and 50°C), while at 70°C in fluidized bed conditions, only about 50% is lost. According to the findings of the experiments, 36–42% of the vitamin C content was maintained at an input temperature of 60°C that was constant and bed conditions that ranged from fixed to fluidized (0.8–3.5 m/s). According to López et al. [26], drying time, pretreatment choice, and processing temperature all affect how much vitamin C is retained. But in order to keep the vitamin C content unaltered, processing temperature is crucial.

β-Carotene is a carotenoid and a fat-soluble pigment. From the results, it was found that the percentage loss of β-carotene was slightly lower when the inlet temperature increased at the same bed conditions. During dehydration of turkey berries, degradation of β-carotene was more noticeable at 50°C with about 40–46% loss with respect to its original value when bed conditions varied from fixed to fluidized (0.8–3.5 m/s). At 60°C, losses of 31–36% were observed, as listed in Table 6, from fixed to fluidized bed conditions, respectively, while during drying at 70°C, losses in the range of 25%–30% occurred. Similar reports from other authors indicate that long drying times influence the loss of this compound [26, 27]. ANOVA carried out for the β-carotene of turkey berries showed significant differences ($P < 0.05$) between the β-carotene retention values of various bed conditions of the dried samples, as presented in Table 6. The significant averages of samples dried at various temperatures (50 to 70°C) were also determined using a multiple comparison test, and it was shown that there were significant changes ($P < 0.05$) when the bed conditions changed from fixed to fluidized (0.8–3.5 m/s).

3.5.4. Retention of Total Phenolic Content (TPC) and Antioxidant Capacity (AOC). From basic phenolic molecules to highly polymerized compounds, phenolic substances all have an aromatic ring with one or more hydroxyl substitutions as part of their structural makeup. The analysis of variance revealed significant differences ($P < 0.05$) in the mean values of the TPC of dried berries under various bed conditions, which are displayed in Table 6. In all nine studies, the TPC retention was best when the sample was dried at an air temperature of 70°C and an air velocity of 3.4 m/s. The dried samples demonstrated a considerable loss of 37.5% in the TPC at 0.8 m/s and 50°C inlet conditions, while at 70°C in fluidized bed conditions, only about 24% is lost, as presented in Table 6. According to the findings of the experiments, 30–33% of the TPC values were maintained at an input temperature of 60°C that was constant and bed conditions that ranged from fixed to fluidized (0.8–3.4 m/s). According to Alkaltham et al. [18], the reduction of TPC during dehydration may be related to polyphenols binding with other substances, such as proteins, or changes in the chemical composition of polyphenols that are not accessible for extraction or analysis. The availability of phenolic molecule precursors resulting from nonenzymatic interconversion between the phenolic molecules may be the cause of the production of phenolic compounds at high temperatures [16–20].

Based on the experimental findings, it was discovered that decreasing the input temperature of the air while maintaining the same bed conditions (0.8 or 3.4 m/s) resulted in a somewhat higher percentage loss of the TAC. As the turkey berry dried, the TAC degraded more noticeably at 50°C, losing 72 to 78% of its original value when the bed condition changed from a fixed to fluidized bed state (0.8–3.5 m/s). From fixed to fluidized bed conditions, losses of 66 to 72% were seen at 60°C, whereas losses in the range of 65 to 60% occurred during drying at 70°C, as presented in Table 6.

The decrease of this antioxidant activity is influenced by long drying times, according to observations from other authors [16–20]. In order to establish the statistically significant difference among the nine samples dried at various temperatures (50 to 70°C), a multiple comparison test was also carried out. The results showed that fewer differences ($P > 0.05$) were seen when the bed conditions varied from fixed to fluidized (0.8–3.5 m/s). The major antioxidants in turkey berries, phenolic compounds and β-carotene, respond to drying temperature, oxygen content, and other processing variables in various ways. The experimental findings indicate a strong link between TPC, vitamin C, and β-carotene and the antioxidant activity of the berries [16–20].

3.6. Microstructural Analysis (SEM). Figure 4 shows the picture and SEM images of the sample skin prior to and after dehydration in FBD. The fresh sample picture and SEM images are depicted in Figures 4(a) and 4(e). The SEM picture of a fresh berry in Figure 4(e) shows a comprehensible vision of the waxy covering on its surface. Whenever the berries are dehydrated at hot air inlet temperatures (above 60°C), the waxy-covered surface begins to disintegrate or break, allowing pores to develop. Figure 4(f) shows a tiny waxy cover and some fragmented wax particles after drying at 50°C. The SEM images of berry peels dried at 60 and 70°C are shown in Figures 4(g) and 4(h). Both Figures 4(g) and 4(h) reveal a decomposed waxy surface layer, as well as micropores and tiny tears upon the peel of the berrydepicted in Figure 4(h).

It is reasonable to conclude that the superior drying rate and numerous micropores are created by high processing temperatures. The surface of the berry exhibits higher porous structures that are formed as a result of the drying of the berries at an incoming air temperature that was high, as observed from the SEM images. High temperature air supplied over the sample, consequently, increases the heat in cells, increasing the internal stress on the cell wall, which may enhance the vapor pressure and result in greater water permeability from the interior of the sample.

As a result of the high-temperature air passing over the sample, the heat in the cells rises, increasing the internal stress on the cell wall. This may increase the vapor pressure, resulting in greater water permeability in the sample's interior. Conversely, at a low processing temperature, insufficient vapor pressure developed, resulting in limited permeability and poor cell structures [14, 33]. Figures 4(a)–4(d) depict photos of fresh fruits and dried samples at 50, 60, and 70°C, and it can be seen that volumetric shrinkage was greater at 50°C (Figure 4(b)) than at 60°C and 70°C (Figures 4(c) and 4(d)).

4. Conclusions

The following results were obtained as a result of the extensive study of turkey berries dried in FBD. The mean value of the initial water content of the turkey berry was computed to be about $5.22 \pm 0.03\%$ (d.b), and the minimum fluidization velocity of the berries in FBD was observed to be 2.1 m/s. The processing temperature plays a predominant role in the course of turkey berry drying compared to the inlet air velocity. High temperature (70°C) and fluidized velocity (3.4 m/s) greatly influence the drying kinetics of turkey berries and improve their physical and chemical properties, such as color and shrinkage, vitamin C, β-carotene, antioxidant capacity, and total phenolic content. The maximum retention rates of vitamin C, β-carotene, antioxidant capacity, and total phenolic content were 1.91 1.91 mg/100 g.d.m, 184 μg/100 g d.m, 21.34 mg AAE/100 g d.m, and 513 mg GAE/100 g, respectively. The maximum effective moisture diffusivity (D_{eff}) and minimum energy required to activate water molecules (E_a) were detected at high temperatures (70°C) and fluidized velocity conditions (3.4 m/s). The drying performance of the sample is far more precisely described by the Midilli et al. model compared to other mathematical models.

Nomenclature

a, b, k, and n:	Model coefficients
W_{st}:	Sample weight at a specific time (g)
W_{dry}:	Sample dry weight (g)
DR:	Drying rate (kg water/kg dry matter. min)
t, t_1, t_2:	Drying time (minutes)
R_p:	Radius of the product (meter)
S_p:	Shrinkage of the product (%)
T_{in}:	Inlet temperature of air (°C)
E_{act}:	Activation energy (m^2/s)
D_0:	Preexponential factor of the Arrhenius equation (m^2/s)
R_{Ug}:	Universal gas constant (kJ/kg-mol/K)
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)
M_{in}:	Initial moisture content of the sample (kg water/kg dry matter)
V_{in}:	Initial volume of the product (m^3)
V_{in}:	Final volume of the product (m^3).

Data Availability

The data supporting the findings of this study are included within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

References

[1] T. K. Lim, *Solanum Torvum. Edible Medicinal And Non-medicinal Plants*, Springer, Dordrecht, Netherlands, 2013.

[2] P. N. Y. Otu, F. Sarpong, J. E. Gidah, A. M. Labanan, and D. Anim, "Characterization of Turkey berry (Solanum torvum)-fresh, dry & powder," *African Journal of Food and Integrated Agriculture*, vol. 1, pp. 9–14, 2017.

[3] D. S. Sivakumar, S. Subramani, N. V. Thirumalai, M. K. Marimuthu, and G. A. Arockiaraj, "Mathematical modeling of thin layer drying characteristics and proximate analysis of Turkey berry (Solanum torvum)," *Thermal Science*, vol. 26, no. 00, 2021.

[4] N. Parlak, "Fluidized bed drying characteristics and modeling of ginger (zingiber officinale) slices," *Heat and Mass Transfer*, vol. 51, no. 8, pp. 1085–1095, 2015.

[5] H. W. Xiao, C. L. Pang, L. H. Wang, J. W. Bai, W. X. Yang, and Z. J. Gao, "Drying kinetics and quality of Monukka seedless grapes dried in an air-impingement jet dryer," *Biosystems Engineering*, vol. 105, no. 2, pp. 233–240, 2010.

[6] S. Erenturk, M. S. Gulaboglu, and S. Gultekin, "The thin-layer drying characteristics of rosehip," *Biosystems Engineering*, vol. 89, no. 2, pp. 159–166, 2004.

[7] C. Srinivasakannan and N. Balasubramanian, "Estimation of diffusion parameters in fluidized bed drying," *Advanced Powder Technology*, vol. 20, no. 4, pp. 390–394, 2009.

[8] R. AmiriChayjan and M. Kaveh, "Physical parameters and kinetic modeling of fix and fluid bed drying of terebinth seeds," *Journal of Food Processing and Preservation*, vol. 38, no. 3, pp. 1307–1320, 2014.

[9] R. Barathiraja, P. Thirumal, G. Saraswathy, and I. Rahamathullah, "Effects of pretreatments on drying of Turkey berry (Solanum torvum) in fluidized bed dryer," *Chemical Industry and Chemical Engineering Quarterly*, vol. 28, no. 3, pp. 169–178, 2022.

[10] R. Barathiraja, P. Thirumal, G. Saraswathy, and I. Rahamathullah, "Drying of Turkey berry in a fluidized bed dryer with mild steel, copper and aluminum inert materials: kinetics and quality determination," *Journal of Mechanical Science and Technology*, vol. 35, no. 6, pp. 2707–2717, 2021.

[11] R. Barathiraja, P. Thirumal, D. Thirumalaikumarasamy, A. Kajavali, M. Ashokkumar, and J. Thiyagaraj, "Investigation of drying kinetics and qualities of Turkey berry in fluidized bed dryer," *Materials Today: Proceedings*, vol. 46, pp. 7711–7718, 2021.

[12] W. Senadeera, B. R. Bhandari, G. Young, and B. Wijesinghe, "Influence of shapes of selected vegetable materials on drying kinetics during fluidized bed drying," *Journal of Food Engineering*, vol. 58, no. 3, pp. 277–283, 2003.

[13] M. Khanali, A. Banisharif, and S. Rafiee, "Modeling of moisture diffusivity, activation energy and energy consumption in fluidized bed drying of rough rice," *Heat and Mass Transfer*, vol. 52, no. 11, pp. 2541–2549, 2016.

[14] S. Aral and A. V. Beşe, "Convective drying of hawthorn fruit (Crataegus spp.): effect of experimental parameters on drying kinetics, color, shrinkage, and rehydration capacity," *Food Chemistry*, vol. 210, pp. 577–584, 2016.

[15] H. Darvishi, "Quality, performance analysis, mass transfer parameters and modeling of drying kinetics of soybean," *Brazilian Journal of Chemical Engineering*, vol. 34, no. 1, pp. 143–158, 2017.

[16] M. Aghbashlo, M. H. Kianmehr, and H. Samimi-Akhijahani, "Influence of drying conditions on the effective moisture diffusivity, energy of activation and energy consumption during the thin-layer drying of berberis fruit (Berberidaceae)," *Energy Conversion and Management*, vol. 49, no. 10, pp. 2865–2871, 2008.

[17] M. P. Zia and I. Alibas, "Influence of the drying methods on color, vitamin C, anthocyanin, phenolic compounds, antioxidant activity, and in vitro bio accessibility of blueberry fruits," *Food Bioscience*, vol. 42, Article ID 101179, 2021.

[18] M. S. Alkaltham, A. M. Salamatullah, M. M. Özcan, N. Uslu, K. Hayat, and I. A. Mohamed Ahmed, "Influence of different drying methods on antioxidant activity, total phenol, and phenolic compounds of myrtle (Myrtus communis L.) fruits," *Journal of Food Processing and Preservation*, vol. 45, no. 4, Article ID e15308, 2021.

[19] Y. Li, P. Li, K. Yang et al., "Impact of drying methods on phenolic components and antioxidant activity of sea Buckthorn (Hippophae rhamnoides L.) berries from different varieties in China," *Molecules*, vol. 26, no. 23, p. 7189, 2021.

[20] I. Taneva and Z. Zlatev, "Total phenolic content and antioxidant activity of yoghurt with goji berries (Lycium barbarum)," *Scientific Study & Research. Chemistry & Chemical*

Engineering, Biotechnology, Food Industry, vol. 21, no. 1, pp. 125–131, 2020.

[21] Aoac, *Official Methods of Analysis*, Assoc Anal Chem, Washington, DC, USA, 1990.

[22] D. Kunii and O. Levenspiel, *Fluidization Engineering*, Butterworth-Heinemann, London, UK, second edition, 1991.

[23] D. V. N. Lakshmi, P. Muthukumar, A. Layek, and P. K. Nayak, "Drying kinetics and quality analysis of black turmeric (Curcuma caesia) drying in a mixed mode forced convection solar dryer integrated with thermal energy storage," *Renewable Energy*, vol. 120, pp. 23–34, 2018.

[24] J. E. Vásquez-Parra, C. I. Ochoa-Martínez, and M. Bustos-Parra, "Effect of chemical and physical pretreatments on the convective drying of Cape gooseberry fruits (Physalisperuviana)," *Journal of Food Engineering*, vol. 119, no. 3, pp. 648–654, 2013.

[25] Aoac, "Official method of analysis," *No.21 Ascorbic Acid in Vitamin Preparation and Juices)*, Association of Official Analytical Chemists, Aithersburg, MD, USA, 17th edition, 2000.

[26] J. López, E. Uribe, A. Vega-Gálvez et al., "Effect of air temperature on drying kinetics, vitamin C, antioxidant activity, total phenolic content, non-enzymatic browning and firmness of blueberries variety O Neil," *Food and Bioprocess Technology*, vol. 3, no. 5, pp. 772–777, 2010.

[27] X. N. Chen, J. F. Fan, X. Yue, X. R. Wu, and L. T. Li, "Radical scavenging activity and phenolic compounds in persimmon (Diospyros kaki L. cv. Mopan)," *Journal of Food Science*, vol. 73, no. 1, pp. C24–C28, 2007.

[28] P. Prieto, M. Pineda, and M. Aguilar, "Spectrophotometric quantitation of antioxidant capacity through the formation of a phosphomolybdenum complex: specific application to the determination of vitamin E," *Analytical Biochemistry*, vol. 269, no. 2, pp. 337–341, 1999.

[29] A. Midilli, H. Kucuk, and Z. Yapar, "A new model for single-layer drying," *Drying Technology*, vol. 20, no. 7, pp. 1503–1513, 2002.

[30] K. Luthra and S. S. Sadaka, "Challenges and opportunities associated with drying rough rice in fluidized bed dryers: a review," *Transactions of the ASABE*, vol. 63, no. 3, pp. 583–595, 2020.

[31] M. Yahya, A. Fudholi, and K. Sopian, "Energy and exergy analyses of solar-assisted fluidized bed drying integrated with biomass furnace," *Renewable Energy*, vol. 105, pp. 22–29, 2017.

[32] M. S. Hatamipour and D. Mowla, "Shrinkage of carrots during drying in an inert medium fluidized bed," *Journal of Food Engineering*, vol. 55, no. 3, pp. 247–252, 2002.

[33] H. C. P. Karunasena, "Scanning electron microscopic study of microstructure of gala apples during hot air drying," *Drying Technology*, vol. 32, no. 4, pp. 455–468, 2014.