



Research Article

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Mathematical Modeling and Characteristics of Apricots During Solar Drying in Uzbekistan

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Abstract

Drying agricultural products in open sun is a conventional practice, often facilitated by solar dryers of various configurations. A recent advancement in this domain is the Forced-air convection solar dryer, tailored specifically for apricot drying. However, the efficacy of this method in Uzbekistan remains inadequately investigated. This study presents a comprehensive experimental and mathematical examination of the convective drying process applied to apricots. Throughout the drying regimen, critical parameters including temperature of drying air, moisture in the air, air flow rate, solar radiation, and mass loss were meticulously monitored at distinct levels within the dryer. Apricots, initially possessing a moisture content of 0.85, were systematically desiccated to an ultimate moisture content of 0.19, with drying durations varying in accordance with solar radiation intensities. Drying time kinetics were scrutinized through both exponential and polynomial functions of humidity ratio. Among the 11 empirical drying models evaluated, the Midelli and Midilli-Kacuk models demonstrated superior fit to our dataset. Additionally, the performance of these mathematical models was assessed through comparison of reduced chi-square (X^2), correlation coefficient (R^2), and root mean square error (RMSE) coefficients. The calculated R^2 and RMSE values for the Midelli et al. and Midilli-Kucuk models stood at (0.9786, 0.04032) and (0.9844, 0.02298) respectively, for both the designed and solar dryers. An empirical model, responsive to process parameters like temperature, relative humidity, and air velocity, was carefully selected and thoroughly analyzed using rigorous statistical methods. This study offers insights into the convective drying of apricots, elucidating the efficiency and applicability of various mathematical models under Uzbekistani conditions. Such findings not only enhance an understanding of agricultural drying processes, but also pave the way for optimized drying practices, thereby fostering sustainability and economic viability within the agricultural sector.

Keywords: Convective Drying; Fruit Drying; Moisture Content Reduction; Solar Energy Utilization; Solar Dryer Efficiency

Introduction

Ensuring the provision of safe food and water is a paramount global challenge in our era. The global food system is currently undergoing a significant transformation driven by factors such as population growth and climate change, which have heightened concerns about affordability and accessibility. These challenges are further compounded by the Russian-Ukrainian warfare, the COVID-19 pandemic, climate shifts, and regional disputes, rendering food safety issues increasingly complex and urgent for the global population.

Food is a fundamental human necessity, and minimizing losses in food processing and distribution is crucial to supporting population growth and maintaining a stable food supply. Inappropriate processing methods and inadequate storage facilities can significantly reduce the quantity and quality of food. This issue is particularly pronounced in many developing countries, where post-harvest losses can be substantial. For

instance, up to 30-40% of harvested fruits and vegetables are lost after harvest [1]. Employing effective drying methods is essential to preserving the quality of fruits, vegetables, and other food products, thereby reducing post-harvest losses [2]. Recent studies have examined the primary factors affecting the quality and drying duration of agricultural products dried using various techniques [3].

Currently, extensive scientific and practical research is being conducted on high-quality storage and processing technologies for fruits, vegetables, grains, and grain products. Researchers such as Mirzayev and Yusufbekov [4], along with Umarov [5], have focused on developing solar devices for drying agricultural products and optimizing their operational parameters [6]. Masharipova and Artikov [6] have investigated the impact of pressure on product drying using ultra-high frequency energy, identifying optimal conditions for this drying method. Additionally, Kushimov and Mamadaliyev [7] have explored energy-saving devices and

technologies for drying fruits, vegetables, and other food products. Onarkulov and Rahmatov [8] have analyzed the efficacy of infrared desiccation in preserving the standard of agricultural goods.

Uzbekistan's fruits, and vegetables, renowned for their taste, high quality, and rich vitamin content, are highly valued. Apricots are a major agricultural product. In 2020, Uzbekistan's apricot exports reached a record level of 74.5×10^4 Mt, making the country the second-largest apricot exporter in the world after Spain [9]. Apricots are consumed fresh, dried, or canned. They facilitate digestion and rapidly remove excess water from the body, making them an excellent dietary fruit. Dried apricots are rich in minerals and vitamins such as iron, carotene, phosphorus, magnesium, and offer benefits for cardiovascular and kidney health. Additionally, apricot juice can strengthen children's immunity and prevent constipation, while oil derived from apricot kernels, used in cosmetics, provides antioxidants that benefit the skin and reduce oxidative stress in body cells [10].

Uzbekistan's climate, characterized by high average temperatures and low humidity, is ideal for sun drying of crops. The northern regions receive an average of 2889 hours of sunshine annually, while the southern regions receive approximately 3095 hours. Figure 1 illustrates the hourly values of direct

solar irradiation in the Tashkent (Uzbekistan) ($41^{\circ}19'24''\text{N}$, $69^{\circ}14'48''\text{E}$).

Figure 1 presents hourly solar radiation values for each month in Tashkent, measured from 5:00 to 20:00.

- **Peak Hours:** The highest radiation values are observed between 11:00 and 15:00.

Seasonal Trends

- **Winter:** Radiation is low in December, January, and February.
- **Spring:** Radiation values increase from March to May.
- **Summer:** Peak radiation occurs in June, July, and August, with the highest value in July at 7248 W/m^2 .
- **Autumn:** There is a gradual decline in radiation from September to November.

Solar Drying Implications

- **Optimal Time:** The most effective drying period during summer is from 10:00 to 16:00.
- **Winter Considerations:** Due to lower radiation, alternative drying methods may be necessary in winter.

Hour	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
5 - 6	0	0	0	0	36	85	36	0	0	0	0	0
6 - 7	0	0	0	76	217	295	261	188	64	8	0	0
7 - 8	0	11	90	224	339	425	418	405	351	159	26	0
8 - 9	119	174	230	325	436	535	537	538	502	337	194	116
9 - 10	246	279	311	404	507	617	625	633	600	423	289	236
10 - 11	302	328	370	453	561	671	685	696	659	483	342	286
11 - 12	334	374	404	479	580	698	718	732	689	519	368	314
12 - 13	356	409	425	486	587	702	726	741	702	551	371	329
13 - 14	352	420	425	473	564	680	716	725	679	506	349	306
14 - 15	311	358	354	429	523	643	676	689	629	437	298	268
15 - 16	250	300	297	369	467	582	613	628	558	355	214	199
16 - 17	81	217	236	299	394	499	534	533	449	194	52	44
17 - 18	0	32	105	209	305	402	425	402	220	18	0	0
18 - 19	0	0	0	32	138	264	255	134	11	0	0	0
19 - 20	0	0	0	0	1	41	23	0	0	0	0	0
Sum	2351	2902	3247	4258	5655	7139	7248	7044	6113	3990	2503	2098

Figure 1: Hourly variation of direct solar radiation in Tashkent (W/m^2) [11].

This data is crucial for optimizing solar drying processes, improving energy efficiency, and preserving agricultural products. Solar drying can streamline the drying process, reduce energy

consumption and transportation costs, and extend the shelf life of products. The main types of solar drying systems for dehumidifying food products are illustrated in Figure 2.

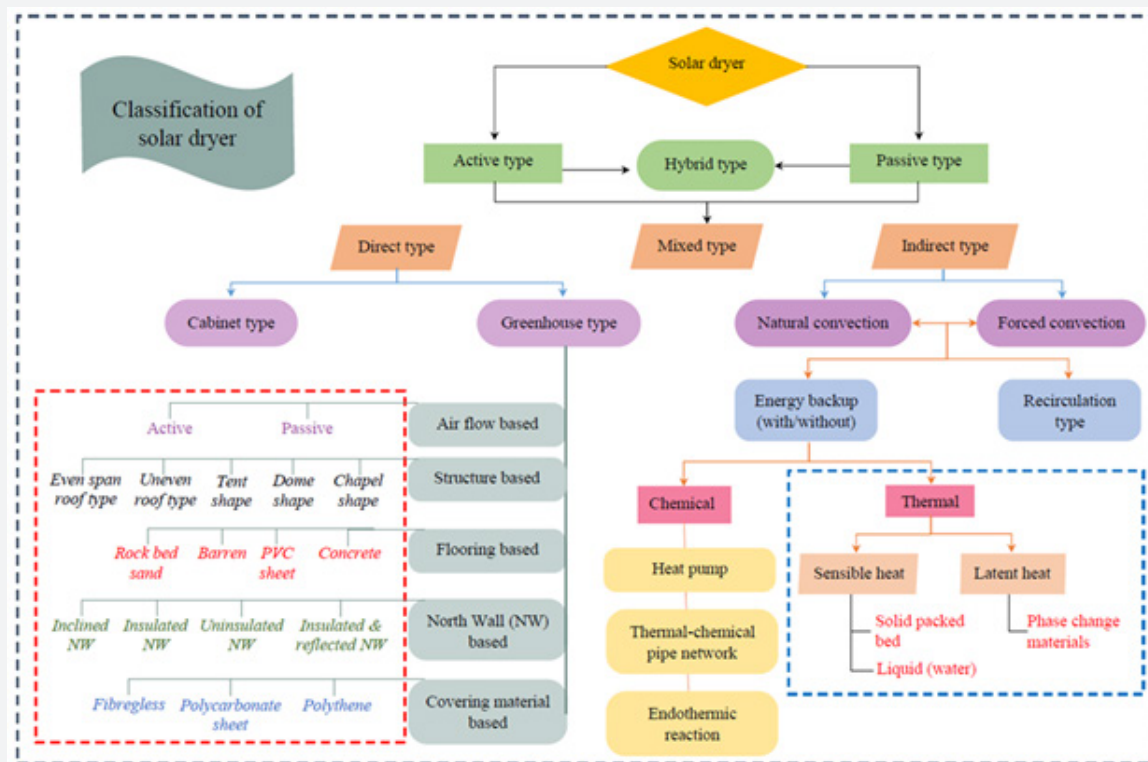


Figure 2: Categories of solar drying systems [12].

By leveraging the peak solar radiation periods and understanding seasonal variations, solar drying methods can be tailored to maximize efficiency and effectiveness, ensuring high-quality preservation of agricultural products.

Figure 2 categorizes solar dryers into active, hybrid, and passive types, each with further subdivisions based on design and energy utilization methods. It outlines various configurations and materials used in cabinet and greenhouse types, highlighting the versatility and adaptability of solar drying technologies across different contexts and conditions. This classification aids in understanding the diverse approaches to solar drying, facilitating the selection of appropriate systems based on specific requirements and environmental conditions.

A controlled solar dryer is proposed as a solution to current challenges in food drying. These dryers, which can operate with natural or forced convection, vary in how they deliver hot air to the products being dried. The main categories of solar dryers consist of direct, indirect, and hybrid solar dryers. Indirect

sun dryers are particularly effective as they can provide more consistent heat, reducing the product's humidity more quickly than other types. These dryers are energy-efficient, compact, and environmentally friendly, emitting no karbonat anhidrid(CO_2), carbon monoxide(CO), nitrogen oxides(NO), or other atmospheric contaminants. Moreover, the dried products are clean, hygienic, and meet international standards.

The chosen air velocities and temperatures reflect those attainable in forced convection solar drying units, aiming to guide the design of these systems. This study investigated how process parameters affect the effective diffusion coefficient and kinetic parameters of different empirical models. By observing alterations in water activity throughout the drying process, the ideal drying duration for each set of circumstances was established. The findings can significantly contribute to the design and implementation of more effective solar drying systems, ensuring better preservation of agricultural products and reducing after-harvest wastage.

Materials and Methods

Materials

Fresh apricots (variety Subhaniy) utilized in this research

were procured from the Chorsu market in Tashkent, Uzbekistan, during the harvesting period. Apricots with similar masses were selected for the drying process. The geometric mean diameter of the wet apricots was approximately 60 mm, and the average weight of the fresh apricots was about 35 g.

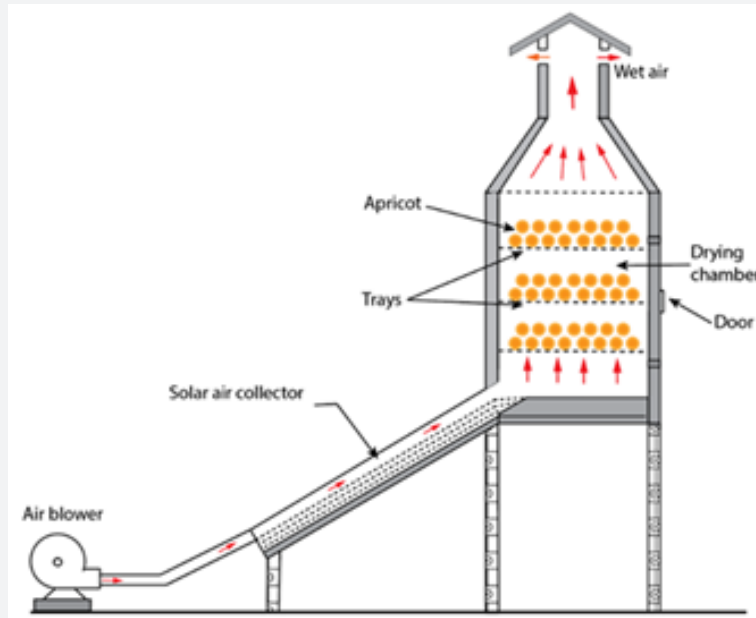


Figure 3: Schematic view of the IFCS system.

Experimental Procedure

Before drying, the apricots' initial moisture content was measured at around 85% (wet basis). The fresh apricots were arranged on a 50 × 80 cm perforated shelf within the drying cabinet. During the drying process, the apricots' weights were regularly monitored using precision scales. Drying persisted until the apricots' final moisture content reached approximately 19% (wet basis). Moreover, the temperature and humidity inside the drying chamber were recorded using a moisture meter and a thermocouple (Figure 3).

The current IFCS system utilized in this study is an integrated setup powered entirely by renewable energy sources. It comprises three main components: a drying chamber, a solar air collector, and a centrifugal air blower.

The drying chamber, constructed from wood, measures 1000 × 600 × 500 mm and contains four trays, each capable of holding up to 2000 g of apricots per drying cycle. The flat solar collector, with dimensions of 2000 × 1000 × 200 mm, provides a surface area of 2 m² and is coated with black paint to maximize solar radiation absorption. A DC blower is installed to enhance the air flow rate at the inlet of the solar air collector. Air is drawn into the solar air collector from the bottom of the drying chamber by the

blower. The heated air then absorbs moisture from the apricots and exits from the top of the desiccation chamber.

Mathematical modeling

Numerous mathematical models for desiccation processes have been proposed in existing literature. This study evaluates several of these models, as listed in Table 1, to analyze the drying process of apricots in the IFCS system.

All models utilized the variables MR for moisture ratio, t for time, k for drying rate constant, and a, b, c, g, and n as model coefficients. Equation 1, was employed for calculating MR during apricot drying.

$$MR = \frac{M_t - M_e}{M_0 - M_e} \quad (1)$$

The initial and final moisture content of apricot was determined using Equations 2 and 3, [19]:

$$M_0 = \frac{m_i - m_d}{m_d} \quad (2)$$

$$M_f = \frac{m_w - m_d}{m_d} \quad (3)$$

where: M_0 - represent initial moisture content (kg H₂O/kg dry matter),

M_f - final moisture content (kg H₂O/kg dry matter)

M_t - transient moisture content (kg H₂O/kg dry matter)

M_e - equilibrium moisture content (kg H₂O/kg dry matter);

m_i , m_d and m_w represent initial mass (kg), dry material mass (kg) and mass of wet mater after drying process.

Table 1: Drying models used for moisture content of apricots.

Model name	Model	Reference
Newton	$MR = \exp(-kt)$	Bahammou et al. [15]
Page	$MR = \exp(-kt^n)$	Koua, et al. [16]
Modified Page	$MR = \exp[(-kt)^n]$	
Logarithmic	$MR = a \cdot \exp(-kt) + c$	Ali, et al. [17]
Henderson and Pabis	$MR = a \cdot \exp(-kt)$	Zhou and Jin [18]
Tow-term	$MR = a \cdot \exp(-k_0t) + b \cdot \exp(-k_1t)$	Lahtasni, et al. [19]
Two term exponential	$MR = a \cdot \exp(-kt) + (1-a) \cdot \exp(-kat)$	Akpınar and Bicer [20]
Midelli at al	$MR = a \cdot \exp(-kt)^n + b \cdot t$	Zhou and Jin [18]
Approximation of diffusion	$MR = a \cdot \exp(-kt) + (1-a) \cdot \exp(-kbt)$	Sacilik, et al. [21]
Verma et al	$MR = a \cdot \exp(-kt) + (1-a) \cdot \exp(-gt)$	Tog'ul and Pehlivan [16]
Midilli - Kucuk	$MR = a \cdot \exp(-kt^n) + b \cdot t$	Ait Mohamed, et al. [22]

Statistical Analysis

To determine the most suitable mathematical models for drying apricot, it is essential to compute three significant statistical metrics: correlation coefficient (R^2) using Equation 4, the chi-square (X^2) employing Equation 5, and the root mean square error (RMSE) as per Equation 6. The model demonstrated the highest R^2 value alongside the lowest X^2 and RMSE values is indicative of the best fit.

$$R^2 = 1 - \frac{\sum_{i=1}^n (MR_{pre,i} - MR_{exp,i})^2}{\sum_{i=1}^n (MR_{exp,i} - MR_{exp,ave})^2} \quad (4)$$

$$X^2 = \frac{\sum_{i=1}^n (MR_{pre,i} - MR_{exp,i})^2}{N - Z} \quad (5)$$

$$RMSE = \sqrt{\frac{1}{N} \sum_{i=1}^n (MR_{pre,i} - MR_{exp,i})^2} \quad (6)$$

In the equations, $MR_{exp,i}$ denotes the normalized moisture ratio observed in the i th experiment, $MR_{pre,i}$ represents the predicted value for the i th observation, $MR_{exp,av}$ stands for the average of normalized moisture ratios among experimental data points, N signifies the total number of experiments, and z denotes the number of constants in the model.

Results and Discussion

Solar Drying Efficiency in Uzbekistan's Climate

Uzbekistan's strong sunlight makes sun drying fruits a convenient and effective method. When sunlight intensity increases from 398 W/m^2 to 886 W/m^2 , the surrounding temperature rises from 25.4°C to 39.1°C , and the collector outlet temperature increases from 33°C to 60°C . The solar collector's heating efficiency peaks at 88 % relative to the ambient air temperature.

The pattern of global solar radiation follows a daily cycle: starting at a lower intensity in the morning, peaking around midday, and gradually decreasing in the afternoon. This variation

influences the efficiency and effectiveness of solar drying processes. By leveraging these climatic conditions, solar drying systems in Uzbekistan can achieve high efficiency, significantly reducing energy consumption and enhancing the quality of dried agricultural products.

Humidity fluctuations during drying process

Figure 4 illustrates the fluctuations in humidity over time during the drying process. Initially, humidity changes gradually for about an hour, followed by a sharp decline. As the drying process nears completion, the humidity levels stabilize. It took around 24 hours to decrease the apricots' initial moisture content from 85 % to 19 %. The timeframe between 10:00 and 16:00 each day was found to be optimal for conducting these experiments.

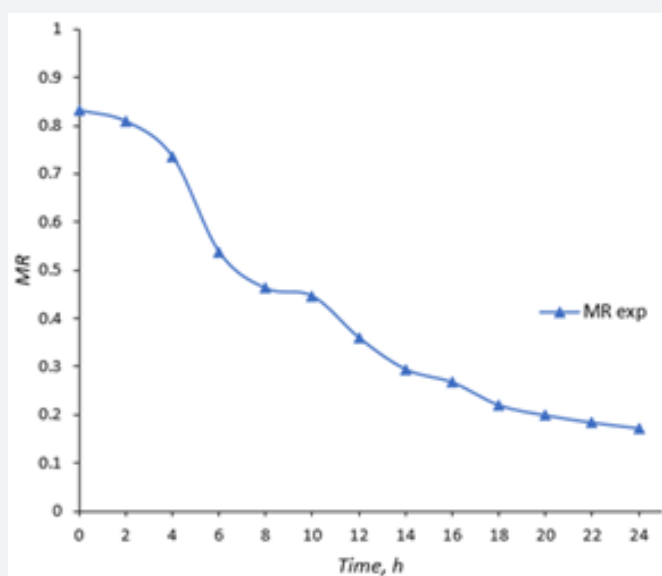


Figure 4: Changes in apricot moisture over time in the experiment.

Model coefficients and statistical metrics

Various model constants and derived statistical parameters, such as the coefficient of determination (R^2), sum of squared errors (X^2), and root mean square error (RMSE), were obtained. The empirical mathematical model with the highest R^2 was chosen as the best fit for apricot drying.

Table 2 presents the constant values (k , n , a , b , c , g) obtained by fitting experimental data to the eleven empirical drying models. Additionally, it displays the statistical parameters calculated using Equations 4, 5, and 6 for the indirect forced cabinet solar drying (IFCSD) of apricots.

Table 2 displays the constant values (k , n , a , b , c , g) obtained

for the eleven models by matching experimental data to empirical drying models. Moreover, it presents the statistical metrics Computed using formulas 4, 5, and 6 for apricot drying in the IFCSD system. The coefficients of the empirical equations were determined using MR results, as depicted in the "cftool" section of Matlab R2018a software (Figure 5).

Model Evaluation and Statistical Analysis

Experimental and predicted values of moisture coefficients under specific drying conditions were compared to validate the established models (Figure 5). Among the 11 empirical drying models applied, the Midelli et al. and Midilli-Kucuk models were selected for further comparison to ascertain the most suitable match. The coefficients for these models were found to be:

• Midelli et al.: ($k = 0.2772$), ($a = 0.8958$), ($n = 0.2584$), ($b = -0.01142$)

• Midilli-Kucuk: ($k = 0.02973$), ($a = 0.8464$), ($n = 1.472$), ($b = 0.006436$)

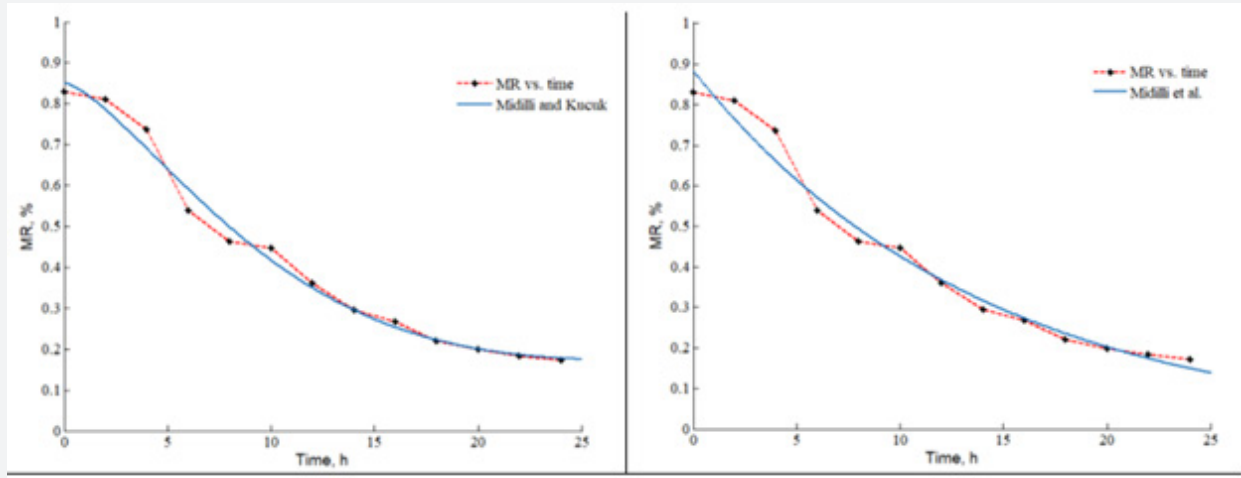


Figure 5: Result of the regression equation for Midelli at al. and Midilli and Kucuk mathematical model.

Table 2: Coefficients and statistical results of mathematical models obtained for apricot drying.

Model name	Model constants	R ²	X ²	RMSE
Newton	$k=0.085$	0.9417	0.03997	0.05771
Page	$k=0.111$, $n=0.8926$	0.9476	0.03589	0.05712
Modified Page	$k=0.5297$, $n=0.1604$	0.9417	0.03997	0.06028
Logarithmic	$k=0.07168$, $a=0.8953$, $c=-0.01097$	0.9786	0.02463	0.04825
Henderson and Pabis	$k=0.0735$, $a=0.8862$	0.9786	0.01466	0.0365
Tow-term	$k_1=0.09117$, $a=-0.009704$, $b=0.8968$, $k_2=0.07377$	0.9786	0.01466	0.04036
Two term exponential	$k=0.1697$, $a=0.3577$	0.9484	0.03535	0.05669
Midelli at al	$k=0.2772$, $a=0.8958$, $n=0.2584$, $b=-0.01142$	0.9786	0.01463	0.04032
Approximation of diffusion	$k=0.1036$, $a=0.9171$, $b=-0.03278$	0.9488	0.03507	0.05922
Verma et al	$k=-0.003926$, $a=0.0818$, $g=0.1034$	0.9488	0.03507	0.05922
Midilli - Kucuk	$k=0.02973$, $a=0.8464$, $n=1.472$, $b=0.006436$	0.9844	0.004753	0.02298

To determine the most precise model for characterizing apricot drying under different conditions, a statistical analysis was performed. The analysis aimed to select the model with the utmost coefficient of determination (R^2) and the least chi-squared (X^2) and RMSE numbers. Essentially, the best-fit model is the one that shows the strongest correlation between predicted and observed values with minimal deviation.

The comparison of experimental and predicted moisture coefficients under specific drying conditions revealed a close

alignment, forming a straight line as shown in Figure 5. The Midilli-Kucuk model demonstrated a satisfactory agreement between experimental and predicted moisture content, with the predicted data generally following a linear trend. This suggests its effectiveness in describing the sun-drying characteristics of apricots. Studying the drying kinetics of apricots is crucial for optimizing dryer operation. For both drying techniques, it was discovered that the Midilli et al. model exhibited the greatest coefficient of determination and the smallest root-mean-

square error. The R^2 and RMSE values for the Midelli et al. and Midilli-Kucuk models were (0.9786, 0.04032) and (0.9844, 0.02298), respectively, for the designed dryer and solar dryer. Therefore, these models effectively portray the apricot drying process, enabling the optimization of operational parameters and enhancing productivity. Mathematical modeling is vital for designing and optimizing drying efficiency, as well as for analyzing and predicting the performance of diverse solar drying systems.

These models are useful for forecasting fruit drying temperature, moisture content, drying rate, and the quality of the desiccated product. However, a key limitation of simple empirical models is their need for different parameters for each set of process conditions, which can be inconvenient for industrial applications where drying conditions might frequently change. The necessity for re-parameterization restricts the model's ability to predict drying behavior outside the specific conditions used for parameter estimation. This limitation is problematic when optimizing drying processes or designing new dryers. Given these limitations, there is a need for more complex models that can account for varying process conditions. Future studies will focus on developing alternative models for apricot drying in Uzbekistan, which can adapt to changes in different process parameters and provide more accurate and versatile predictions.

Conclusion

This study has investigated the drying procedure of apricots using an indirect forced cabinet solar drying (IFCSD) system, employing a combination of experimental and mathematical analyses. It was found that fluctuations surrounding conditions, like temperature, air humidity, and pollutant levels, significantly impact both the drying duration and the quality of the dried product. In arid regions like Uzbekistan, rehydration during processing is less of a concern, whereas in areas with higher humidity, the risk of microbial growth increases due to elevated water activity in the dried product.

Within the IFCSD system, all eleven analyzed models provided similarly effective descriptions of the experimental data, thanks to the stable conditions maintained within the system. However, parametric methodologies such as the Midelli et al. and the Midilli-Kucuk models consistently outperformed other approaches. Among the eleven empirical drying models applied, the Midelli et al. and Midilli-Kucuk models best fit our data.

Among the 11 empirical drying models evaluated, the Midelli and Midilli-Kacuk models demonstrated superior fit to our dataset. Additionally, the performance of these mathematical models was assessed through comparison of reduced chi-square (X^2), correlation coefficient (R^2), and root mean square error (RMSE) coefficients. The calculated R^2 and RMSE values for the Midelli et al. and Midilli-Kucuk models stood at (0.9786, 0.04032) and (0.9844, 0.02298) respectively, for both the designed and solar dryers. An empirical model, responsive to process parameters like temperature, relative humidity, and air velocity, was carefully

selected and thoroughly analyzed using rigorous statistical methods. The effectiveness of these mathematical models was evaluated by comparing the correlation coefficient (R^2) reduced chi-square (X^2), and root mean square error (RMSE) coefficients. For the designed dryer and solar dryer, the R^2 and RMSE values were (0.9786, 0.04032) and (0.9844, 0.02298), respectively, for the Midelli et al. and Midilli-Kucuk models. An empirical model, capable of responding to process variables such as temperature, air velocity, and relative humidity, was carefully selected and then subjected to thorough statistical analysis.

This study offers insights into the convective drying of apricots, elucidating the efficiency and applicability of various mathematical models under Uzbekistani conditions. Such findings not only enhance an understanding of agricultural drying processes, but also pave the way for optimized drying practices, thereby fostering sustainability and economic viability within the agricultural sector.

References

- Madhankumar S, Viswanathan K, Taipabu MI, Wu W (2023) A review on the latest developments in solar dryer technologies for food drying process. *Sustainable Energy Technologies and Assessments* 58: 103298.
- (2024) Apricot Production by Country 2024.
- Usmanov BSH, Kushiyeu XX, Nuriyev KK, Raxmatov O, Yusupov AM, "Solar dryer."
- Mirzayev SM, Qodirov JR, Hakimov B (2022) Creating a solar device for drying apricots in solar devices and researching its mode of operation.
- Umarov GG, Mirziyayev SHM, Yusupbekov ON (1994) Solar dryer for agricultural products. Tashkent Fan.
- Masharipova ZA, Artikov AA, Rakhmatov FO (2020) Computer modeling of drying processes and calculation of optimal conditions. Tashkent.
- Kushimov B, Mamadaliyev X (2021) Energy-efficient equipment and technology for drying agricultural and fruit-vegetable products," *Oriental Renaissance: Innovative, educational, natural and social sciences*.
- Onarqulov K, Raxmatov G, Xoldorov M (2023) Some analyzes of infrared drying and quality preservation of agricultural products," *Oriental Renaissance: Innovative, educational, natural and social sciences*.
- Рахматов О, Рахматов ОО, Рахматов О (2015) Combined action solar dryer for small farms. Problems of increasing the efficiency of using electrical energy in the agro-industrial complex.
- Ginzburg AS (1973) Fundamentals of the theory and technology of drying food products.
- (2024) Global Solar Atlas.
- Goel V (2024) Solar drying systems for Domestic/Industrial Purposes: A State-of-Art review on topical progress and feasibility assessments. *Solar Energy* 267: 112210.
- Nimnuan P, Nabnean S (2020) Experimental and simulated investigations of the performance of the solar greenhouse drer for drying cassumunar ginger (*Zingiber cassumunar Roxb.*). *Case Studies in Thermal Engineering* 22: 100745.
- Fudholi A, Sopian K, Yazdi MH, Ruslan MH, Gabbasa M, et al. (2014) Performance analysis of solar drying system for red chili. *Solar Energy* 99: 47-54.

15. Bahammou Y, Tagnamas Z, Lamharrar A, Iddimam A (2019) Thin-layer solar drying characteristics of Moroccan horehound leaves (*Marrubium vulgare* L.) under natural and forced convection solar drying. *Solar Energy* 188: 958-969.
16. Koua KB, Fassinou WF, Gbaha P, Toure S (2009) Mathematical modelling of the thin layer solar drying of banana, mango and cassava. *Energy* 34(10): 1594-1602.
17. Ali I, Abdelkader L, El Houssayne B, Mohamed K, El Khadir L (2016) Solar convective drying in thin layers and modeling of municipal waste at three temperatures. *Applied Thermal Engineering* 108: 41-47.
18. Zhou Y, Jin Y (2016) Mathematical Modeling of Thin-layer Infrared Drying of Dewatered Municipal Sewage Sludge (DWMSS). *Procedia Environmental Sciences* 31: 758-766.
19. Lahsasni S, Kouhila M, Mahrouz M, Iddimam A, Jamali A (2004) Thin layer convective solar drying and mathematical modeling of prickly pear peel (*Opuntia ficus indica*). *Energy* 29(2): 211-224.
20. Akpinar EK, Bicer Y (2008) Mathematical modelling of thin layer drying process of long green pepper in solar drier and under open sun. *Energy Conversion and Management* 49(6): 1367-1375.
21. Sacilik K, Keskin R, Elicin AK (2006) Mathematical modelling of solar tunnel drying of thin layer organic tomato," *Journal of Food Engineering* 73(3): 231-238.
22. Ait Mohamed L, Ethmane Kane CS, Kouhila M, Jamali A, Mahrouz M, et al. (2008) Thin layer modelling of *Gelidium sesquipedale* solar drying process. *Energy Conversion and Management* 49(5): 940-946.



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