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Solar drying experimental research and mathematical modelling of wild mint and peach moisture content

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ABSTRACT

This research may be seen in the solar drying of several mature plants. Fruits and vegetables such as peaches and wild mint are grown in a semi-arid region near Quetta, Pakistan. Our research is confined to determining the volume of moisture removed from the distinct items and employing forced convection using three distinct mass flow rates to regulate the pace of the solar dryer, which enables us to further our study and improve the influence of mass flow rate on the quantity of water extracted from the item. A series of mathematical models for different scientists, based on the mathematical connection used, and by determining the constants for each model, which implies that each mass flow correlates to the constants of the five models, and thus the product ultimately influences them in terms of type, shape, and mass. The findings were upgraded, and analyzed the mathematical models of the scientists with our approach, which was likewise quite accurate. We infer that the mass flow rate has an effect on the coefficients of the developed model, and it is an essential component. The model may be used to forecast the moisture content of peach and wild mint during the drying system.

Contribution/ Originality: The research paper on the mathematical modeling of the dryness of peach and wild mint with mass flow rate introduces a unique and original approach to studying the drying process. By incorporating mass flow rate into the model, the researchers can accurately predict the drying kinetics and final moisture content of the dried product with greater precision. This novel approach provides valuable insights into the drying process and can be applied to other drying systems, making it a useful tool for improving and controlling the drying process in various industries.

1. INTRODUCTION

The sun drying is an important sector of drying agriculture, and it was outflow the vital percent moisture by solid of agricultural parts [1]. Several researchers have focused in the volume of pieces or the surface, and some were concerned in the thickness of the product employed [2]. Throughout this research, we chose the mass flow rate as an essential aspect in the solar dryer of wild mint and peach, which was sliced into virtual small pieces, and we are attempting to construct a mathematical model to calculate the moisture ratio of wild mint and peach and compare it to other models. some scientists worked to build a forced convection solar dryer employing an evacuated tube air collector [3]. Its efficiency was evaluated to that of ambient sun drying [4]. As per the findings of this research, the suggested solar drier is more efficient, and the moisture content of plump is decreased from 91 percent to 6.25 percent in 6 hours as opposed to 10 hours in natural sun drying [5].

Further article examines an experimental investigation that was carried out to compare the performance of a simply solar cabinet dryer and a technology fitted with a supplementary furnace as a support to the sun drying system [6]. Both systems' result is evaluated to that of natural drying. Two parallel - plate collectors, a blower, as well as a dehumidifier are being used to dry beans and peas [7]. Four alternative airflow rates were investigated, specifically 0.0383, 0.05104, 0.0638, and 0.07655 m^3/s were carried out. When compared to simply sun drying, the performance of the hybrid drying system improved by 25-40%. Six exponential equations for the various systems with correlation coefficients ranging from 0.933 to 0.997 provided the best match to the experimental data of peas and beans. Open sun drying might be an excellent method of food preservation [8] because the product is totally sheltered from rainfall, dirt, bugs, and animals during drying [9].

There is indeed a wide range of models and techniques of operation [10] induced indirect convection [11] sun dryers using direct and indirect modules [12] the Co-Gen technology improves the performance of a solar-biomass hybrid dryer [13] sun dryers for greenhouses [14] direct sun drying system [15] heat transfer processes [16] Sun dryers with indirect natural convection and chimneys, sun dryers with greenhouse sources, solar assisted tunnel dryers and solar powered hybrid dryers [17] containing evacuated tube compilations [18]. The collector performance in a single cycle of a solar air heater with and without blades attached underneath the absorptive tray was studied analytically [19] as well as the highest efficiency gained for the 0.012 and 0.016 kg/s with and without blades were 40.02, 51.50 percent and 34.92, 43.94 percent, respectively. The research was carried out on a configuration for indirect double-pass packed bed-forced convection solar distillation [20] that measured the dryness of lemon balm leaves. We may change the mass flow rate of air in the sun drying process and observe the result with the outlet temperature, moisture levels, as well as statistically findings of mathematical modeling of dryness slopes of lemon balm leaves [21]. The reported research was conducted to determine an indirect sun drier in order to optimize storability for potato slices. Throughout the whole investigation, researchers tried to improve the efficiency of their sun drying system by employing photovoltaic panels to increase heat efficiency and tracking the influence of various hybrid solar dryer regulating elements on the taste of dehydrated sliced potatoes [21]. Several research employed mathematical modelling to investigate the effective moisture diffusivity of tomatoes while heated air sun drying. Investigations were performed out in a thin sheet warm air drying chamber at slicing sizes of 3, 5, and 7 mm having velocity of the air of 0.5, 1 and 2 m/s [22]. A photovoltaic (PV) Solar system powered mixed-mode solar tunnel drier was used to study the drying of potato chips. The solar tunnel drier (STD), efficiency has been assessed with and without loading, as well as with and without a thermal barrier over sliced potatoes on sunshine hours, adopting varied airflow rates (2.1, 3.12, and 4.18 m^3/min) and pretreatments on sliced potatoes [23]. A study was conducted to evaluate the influence of air temperature, wind velocity, and test morphologies on the kinetic drying of sliced potatoes in a tunneling drier, and an appropriate dryness framework was established. The studies were carried out at 45-70°C air temperatures and air speeds of 1.60 and 1.81 m/s [24]. Another research used sun drying of potatoes sliced into three distinct configurations: cylindrical, cubical, and rectangular, with almost the same volume, and utilizing the modelling approach and experimental drying kinetics curves [25].

2. INVESTIGATION THROUGH EXPERIMENTATION

We concentrated on agro-food drying in this research, employing a solar panel as well as a de-humidifier. The chamber was constructed of various materials such as timber and was insulated on all surfaces. It was linked to the solar module by a pipeline that circulated air via openings to spread air on the dried product; its dimensions were 75cm × 45cm × 45 cm. We drilled holes to spread airflow on the product and prevent it from burning. In this arrangement, we drilled 8mm holes in a 25cm by 25 cm square sheet. The grating is a framework for the product that has holes for water drainage and is linked by four poles that are stabilized to permit us to weigh the product without detaching it. The panel is distinguished by its toughness and corrosion resistance.

3. DRYING CURVE MATHEMATICAL MODELING

Before being transformed to kilos of water per kilogram of dry mass, the relative humidity was reported as a percentage of the wet basis. As shown in Table 1, these curves were then adjusted to five different moisture ratio models to generate a good framework for characterizing the drying process of wild mint and peach.

Table 1. A mathematical model used to analyze the drying trends.

References	Models	Equations
Lahsasni, et al. [26]	Logarithmic	MR = a exp(−kt) + c
Dandamrongrak, et al. [27]	Two term	MR = a exp(−kt) + cexp(−gt)
Hayaloglu, et al. [28]	Two term exponential	MR = a exp(−kt) + (1−a)c exp(−kat)
Hayaloglu, et al. [28]	Wang and Singh [29]	MR = 1+ at+ct^2
Hayaloglu, et al. [28]	Midilli, et al. [30]	MR = a exp(−kt) + ct

Equation 1 represented the moisture ratio (MR) while drying.

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

Therefore, by updating Equation 1 to $\frac{M_t}{M_0}$, instead of $\frac{M_t - M_{eq}}{M_0 - M_{eq}}$ [31]. The key requirements for choosing the optimal equation to adjust for variance in the drying curves of the dried samples were the minimized Chi-square (χ^2) as well as Root Mean Square error (RMSE). The lower the (χ^2) value, the higher the quality of fit. The (RMSE) is the difference between the anticipated and actual values, and it must be equal to zero. Equations 2 and 3 were used to compute the statistical parameters.

$$(\chi^2) = \frac{\sum_{i=1}^{N}(M_{exp,i} - M_{mod.i})^2}{N-m} \quad (2)$$

$$RMSE = (\frac{1}{N}\sum_{i=1}^{N}(M_{exp,i} - M_{mod,i})^2)^{\frac{1}{2}} \quad (3)$$

There is indeed a strong connection with the correlation coefficient when standard observations and predictions are utilized as (RMSE) inputs. If somehow the correlation coefficient would be one, the RMSE value will be zero as all of the observations are on the regression line (thus no errors):

$$SSE = \frac{1}{N}\sum_{i=1}^{N}(M_{exp,i} - M_{mod,i})^2 \quad (4)$$

The least squares technique is a common strategy in regression model for estimating the outcome of overdetermined problems as described in Equation 4. The term "least squares" refers to the entire response reducing the sum of the squares of the residuals calculated from the outcomes of each individual equation.

Throughout this research, the model was constructed in sinusoidal pattern with the constants a, c, k, and g regressed against dehydrating air temperatures as well as mass flow rate then obtained through multiple regression modeling as described in Equation 5. After performing multiple regression analysis, the following model was chosen:

$$\frac{M_t - M_{eq}}{M_0 - M_{eq}} = c + a \times \sin\left(\pi \frac{(t-k)}{g}\right) \quad (5)$$

Table 2 summarizes the findings of nonlinear regression model for drying curve fitting based on the wild mint for several models. Logarithmic, Two-term exponential and Wang as well as Singh were chosen as the best fitting in our created model. At our model, we have the perfect maximum coefficient of determination and the smallest value of χ^2 and RMSE as well as Wang and Singh [29].

Table 3 displays the various moisture content models for the appropriate peach product. In our constructed model as well as other methods such as Logarithmic, Wang and Singh [29], and Midilli, et al. [30], it has been chosen a maximum value of the coefficient of determination R^2 of 0.9913, 0.9939 and 0.9826, respectively.

Here the developed model receives the best χ^2 test by 0.0006. Tables 2-3 show the findings of statistical computations performed to determine the reliability of five drying models for three variable mass flow rate each model.

Table 2 Nonlinear regression model resulted for drying curve fitting in accordance with wild mint.

Models	S. n0	R^2	RMSE	(SSE) sum of squared errors	χ^2	a	c	g	k
Logarithmic	1	0.994	0.136	0.016	0.019	2.43	−1.405		0.004
	2	0.993	0.030	0.001	0.001	1.126	−0.1058		0.02
	3	0.981	0.053	0.002	0.003	1.144	−0.11		0.02
Two term	1	0.946	0.091	0.006	0.009	0.204	0.871	0.015	0.02
	2	0.986	0.051	0.002	0.003	0.519	0.52	0.018	0.02
	3	0.972	0.071	0.003	0.006	0.526	0.526	0.019	0.02
Two-term exponential	1	0.946	0.091	0.005	0.009	0.984	5.552		0.02
	2	0.997	0.024	0.001	0.001	1.93	1.01		0.03
	3	0.992	0.037	0.001	0.002	2.086	1.002		0.028
Wang and Singh [29]	1	0.994	0.047	0.001	0.002	−0.01	0.0003		
	2	0.999	0.013	0.001	0.001	−0.012	0.0001		
	3	0.944	0.029	0.001	0.001	−0.013	0.0001		
Midilli, et al. [30]	1	0.993	0.144	0.018	0.021	1.025	−0.003		0.007
	2	0.985	0.047	0.001	0.003	1.061	−0.0002		0.0181
	3	0.953	0.085	0.003	0.008	1.099	−0.0001		0.022

Table 3. Nonlinear regression model resulted for drying curve fitting in accordance with peach.

Models	S. n0	R^2	RMSE	(SSE) sum of squared errors	χ^2	a	c	g	k
Logarithmic	1	0.959	0.075	0.005	0.006	1.567	−0.572		0.005
	2	0.948	0.093	0.008	0.009	1.601	−0.554		0.006
	3	0.992	0.034	0.001	0.002	1.401	−0.397		0.0006
Two term	1	0.922	0.108	0.01	0.012	0.527	0.527	0.01	0.01
	2	0.908	0.13	0.014	0.017	0.552	0.552	0.012	0.012
	3	0.965	0.075	0.005	0.006	0.529	0.529	0.012	0.012
Two-term exponential	1	0.921	0.109	0.010	0.012	0.016	1.06		0.639
	2	0.907	0.131	0.014	0.017	0.006	1.11		2.1402
	3	0.964	0.075	0.005	0.006	0.005	1.058		2.5837
Wang and Singh [29]	1	0.963	0.072	0.004	0.006	−0.007	0.00001		
	2	0.955	0.09	0.007	0.008	−0.008	0.0001		
	3	0.994	0.029	0.001	0.001	−0.008	0.0001		
Midilli, et al. [30]	1	0.956	0.077	0.005	0.006	1.022	−0.001		0.0069
	2	0.934	0.104	0.01	0.011	0.986	−0.01		0.0039
	3	0.983	0.048	0.002	0.003	1.06	−0.001		0.0098

Tables 2-3 indicate the fact that the mass flow rate has the greatest influence on the model coefficients. Our constructed model Wang and Singh [29] and Midilli, et al. [30] had the best greatest value of the coefficient determination of the R^2. The model depicts the model selection assessment, which begins with providing data for various factors such as the moisture content of each product and subsequently the drying time as shown in Figure 1.

In the second stage of the method test, we utilized regression analysis to determine the constants (a, c, g, and k) by the parameter individually including such drying rate, and we jumped directly verify the anticipated coefficient determination R-squared.

In the third section, we have been using the constructed model in sinusoidal shape to fit moisture content data sets as a function of drying time to find the constant value of the fitting predict equation.

4. RESULTS AND ANALYSIS

Figure 2 depicts the fluctuation in the drying chamber's input temperature over time and according to varying parameters of mass flow rate. It is clear that at low mass flow rates and high mass flow rates, the inlet temperature varies between maximum and lowest values. The wild mint and apricot trials, it was found that the first mass flow rate attempt, m = 0.016 kg/s, was the best one due to the maximum temperature measurements, and the temperature difference between the second and third trials, m = 0.025 and 0.030 kg/s, had the smallest difference. The temperatures reached 70°C during the first test and 64°C on the second test as shown in Figure 2.

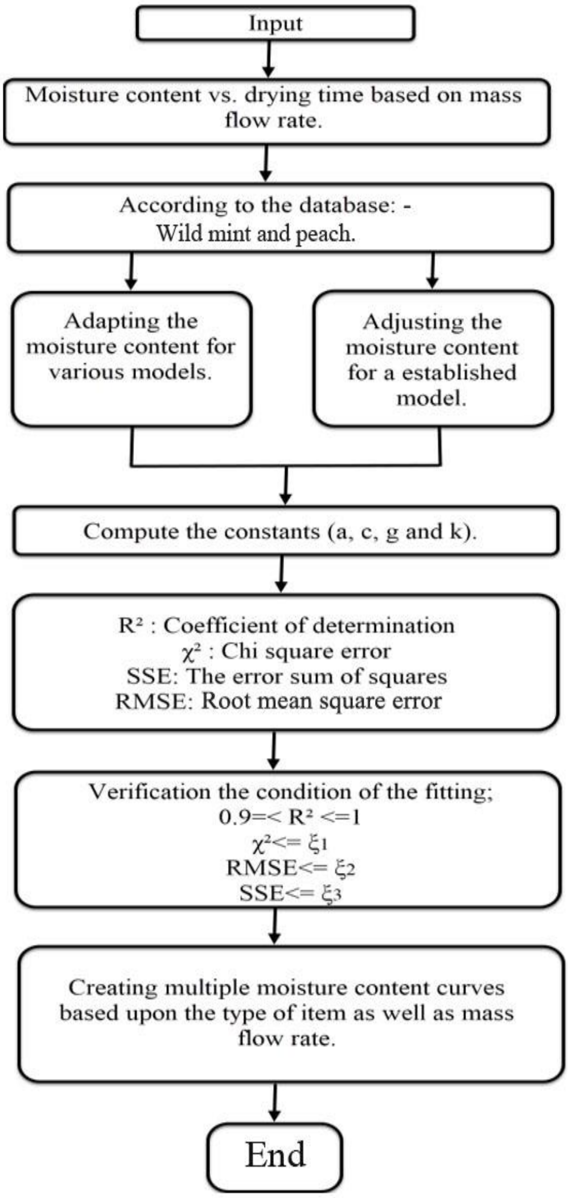


Figure 1. Fitting model schematic representation.

The curve illustrates how Moisture Ratio (MR) varies with time for several models in comparison to the experimental model. It must be observed that all models exhibit the same diminishing shape when the product dries as shown in Figure 3. The rate of mass flow affects variables like the drying product's and drying chamber's intake temperature. Figure 2 shows that the minimal mass flow rate causes the inlet temperature to reach its maximum value.

The graph below compares the fluctuation of MR with a mass flow rate of m = 0.016 kg/s to the suggested model. The suggested model is congruent with existing models, as can be observed. The expansion of the moisture content of the wild mint and peach product was connected to radiation from the sun and indeed the heating of the solar collector, primarily relies on radiation from the sun absorption and associated test regions.

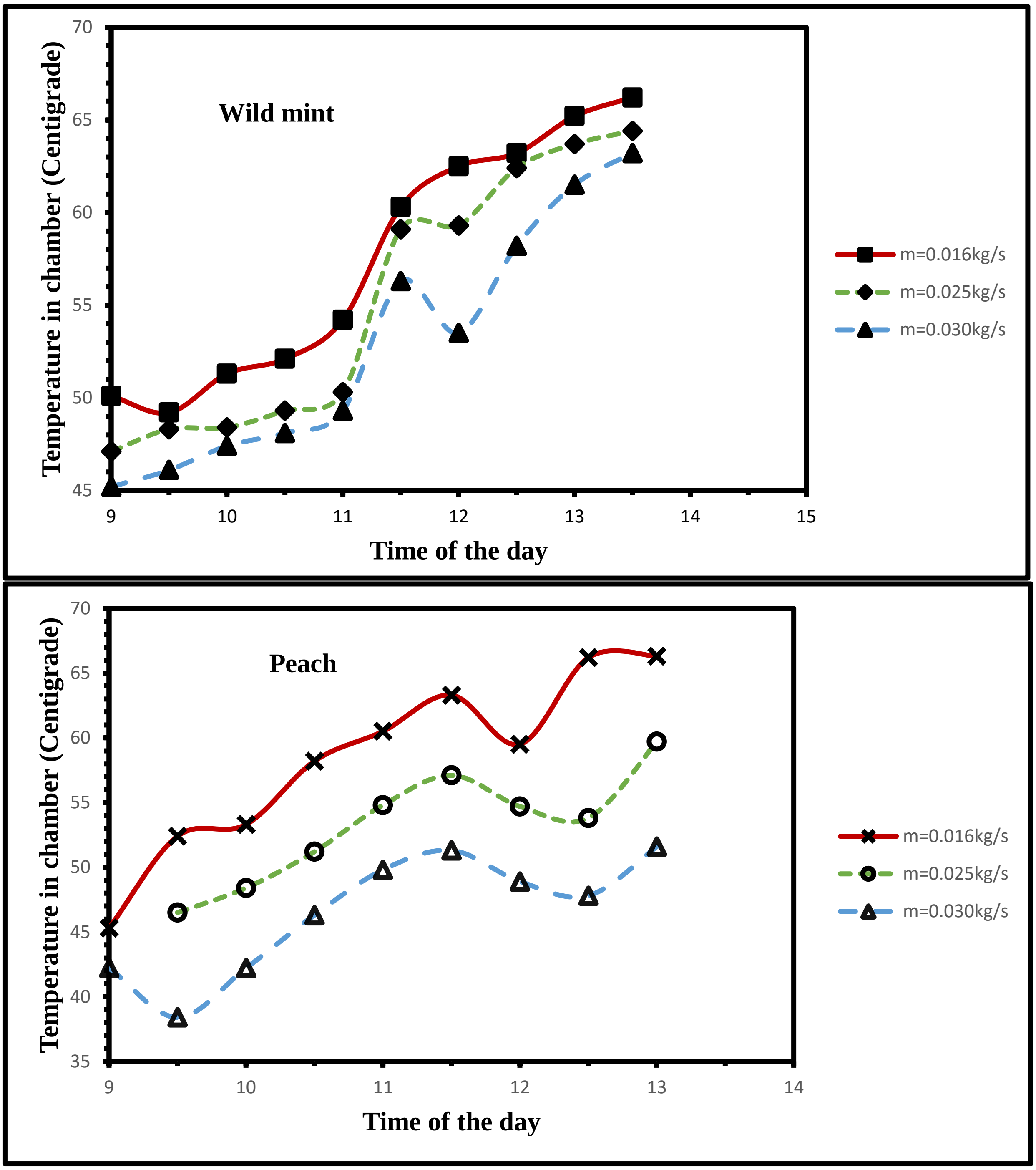
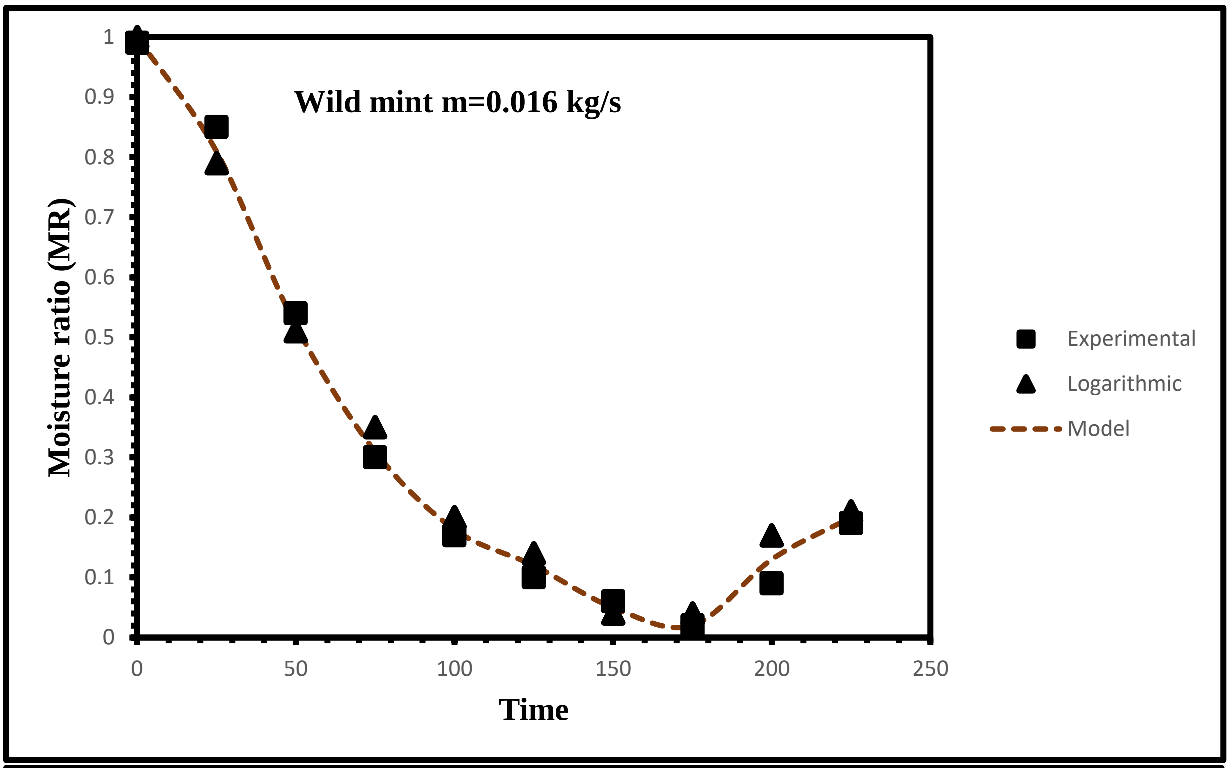


Figure 2. The drying chamber's inlet temperature is set by the mass flow rate.



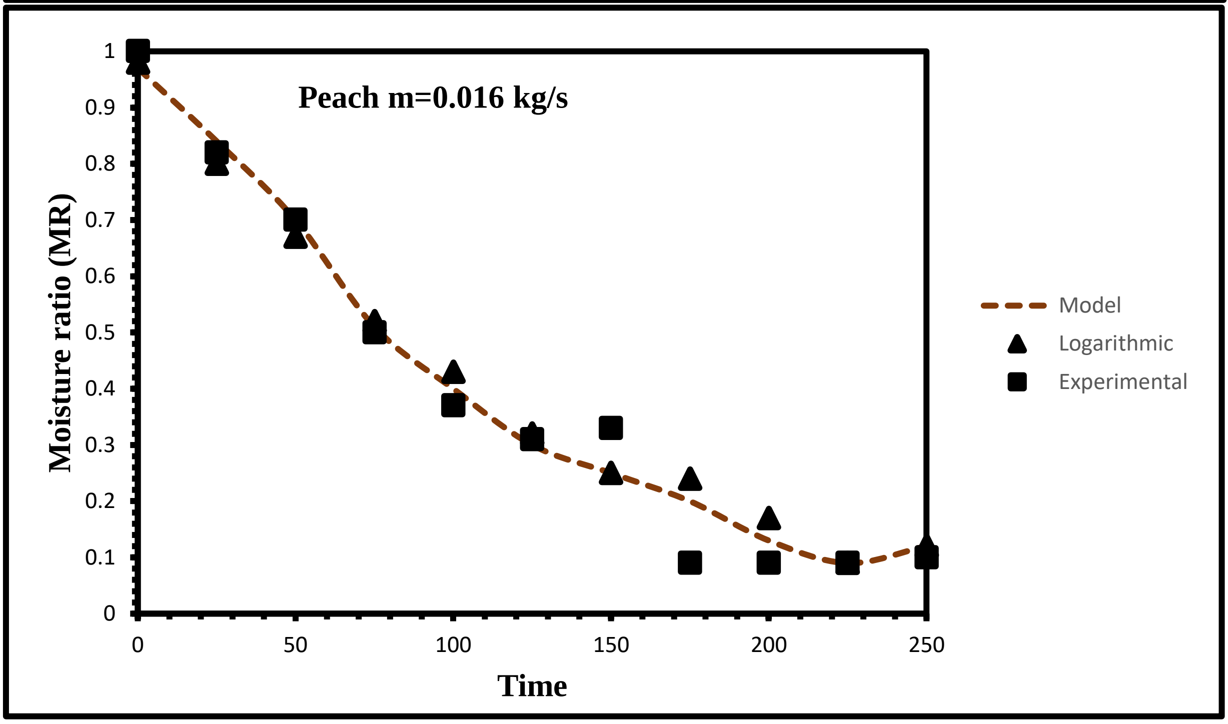


Figure 3. The Moisture content calculated using Logarithmic models as well as experimental measurements at a mass flow rate of 0.016 kg/s.

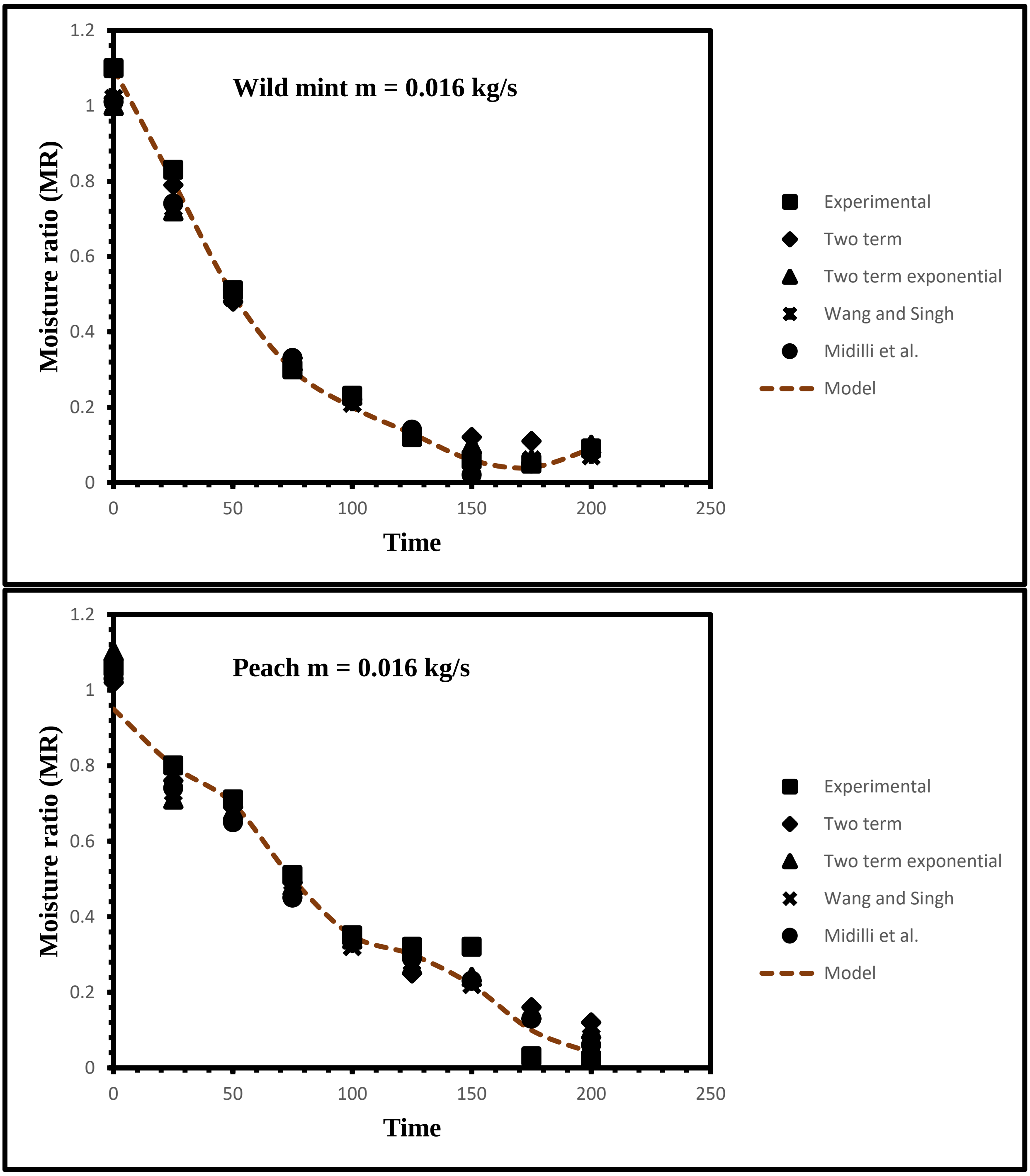


Figure 4. The moisture was determined using the two-term, two-term exponential, Wang and Singh [29], Midilli, et al. [30], prediction model, using experimental data at a mass flow rate of 0.016 kg/s.

The constants of the models are affected by the kind of product and indeed the mass flow rate, which explains how the curves vary as the product type changes as shown in Figure 4.

Figure 5 depicts a comparison of the two models with a mass flow rate of 0.025 kg/s. It needs to be noticed that the drying time increases with expected growth. However, the curves' progression retains the same shape.

Figure 5 and 6 show how the evolution of the curves varies with changing the product and subsequently the mass flow rate, and how this impact adds to the argument that the model constructed varies with this effect as well.

While at the same period, we observe that various models provide different outcomes when the mass flow rate changes; this section demonstrates that the constants of the projected models have different values in the same product with different mass flow rates. A dispersion between the models occurs at increased throughput. The suggested model is more accurate than the experimental curve.

The experimental model's drying curve has a distinct form in Figure 7 and at a mass flow rate of 0.030 kg/s. The first phase heating up appears. This is not true for all models.

We see that, for this mass flow, the suggested model's variation curve of MR as a function of time follows the development of the experiment. The figure depicts the suggested model's improved performance in terms of the best translation of this dryness occurrence with this product. Figure 7 and 8 show the curves of reduced moisture ratio MR as a function of time for peach and wild mint, as established by the derived framework, of logarithmic and experimental data with a mass flow rate of 0.030 kg/s and all of those experimentally measured, with each illustration expressing a variety of products.

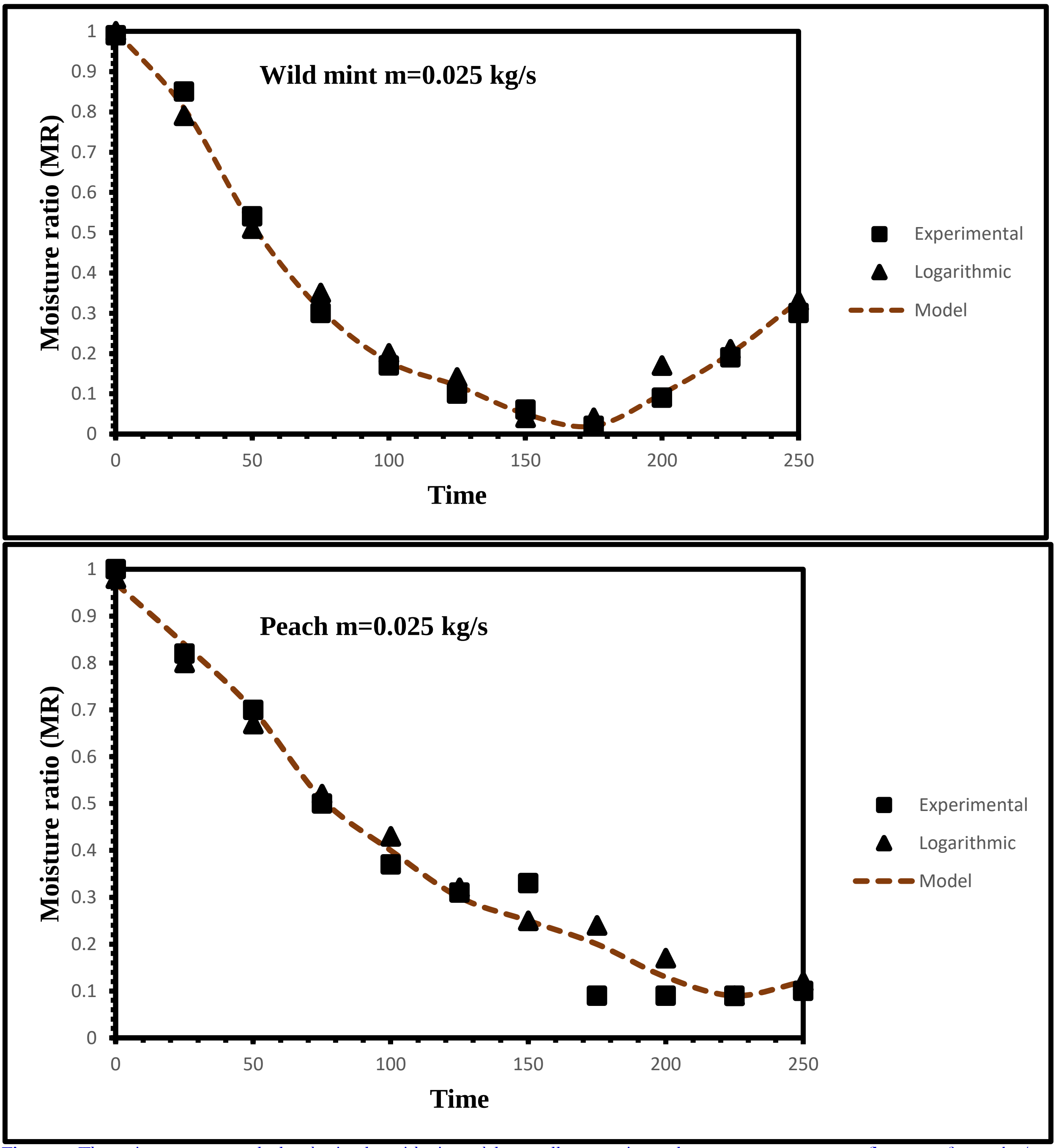


Figure 5. The moisture content calculated using logarithmic models as well as experimental measurements at a mass flow rate of 0.025 kg/s.

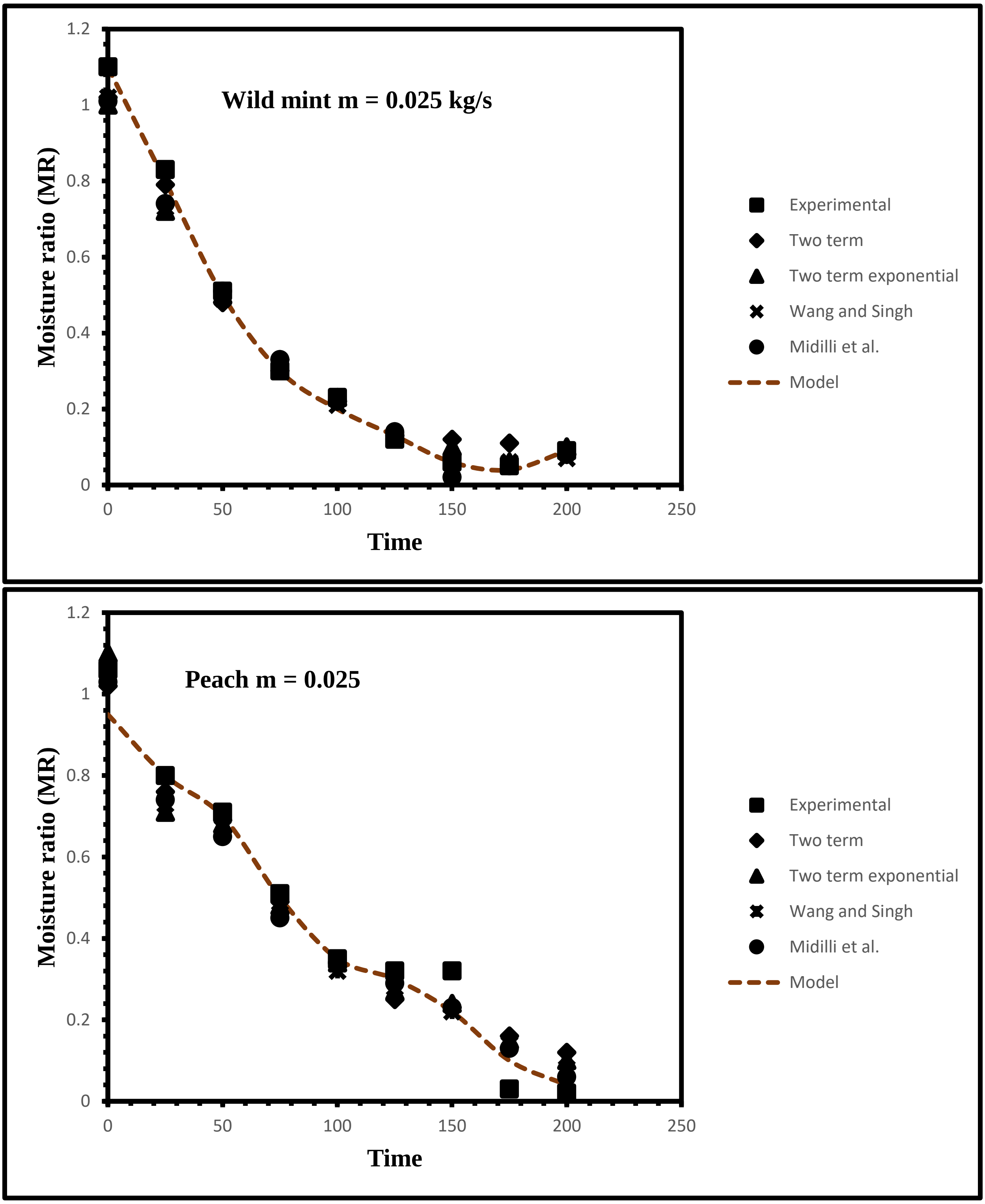


Figure 6. The moisture was determined using the two-term, two-term exponential, Wang and Singh [29], Midilli, et al. [30], prediction model, using experimental data at a mass flow rate of 0.025 kg/s.

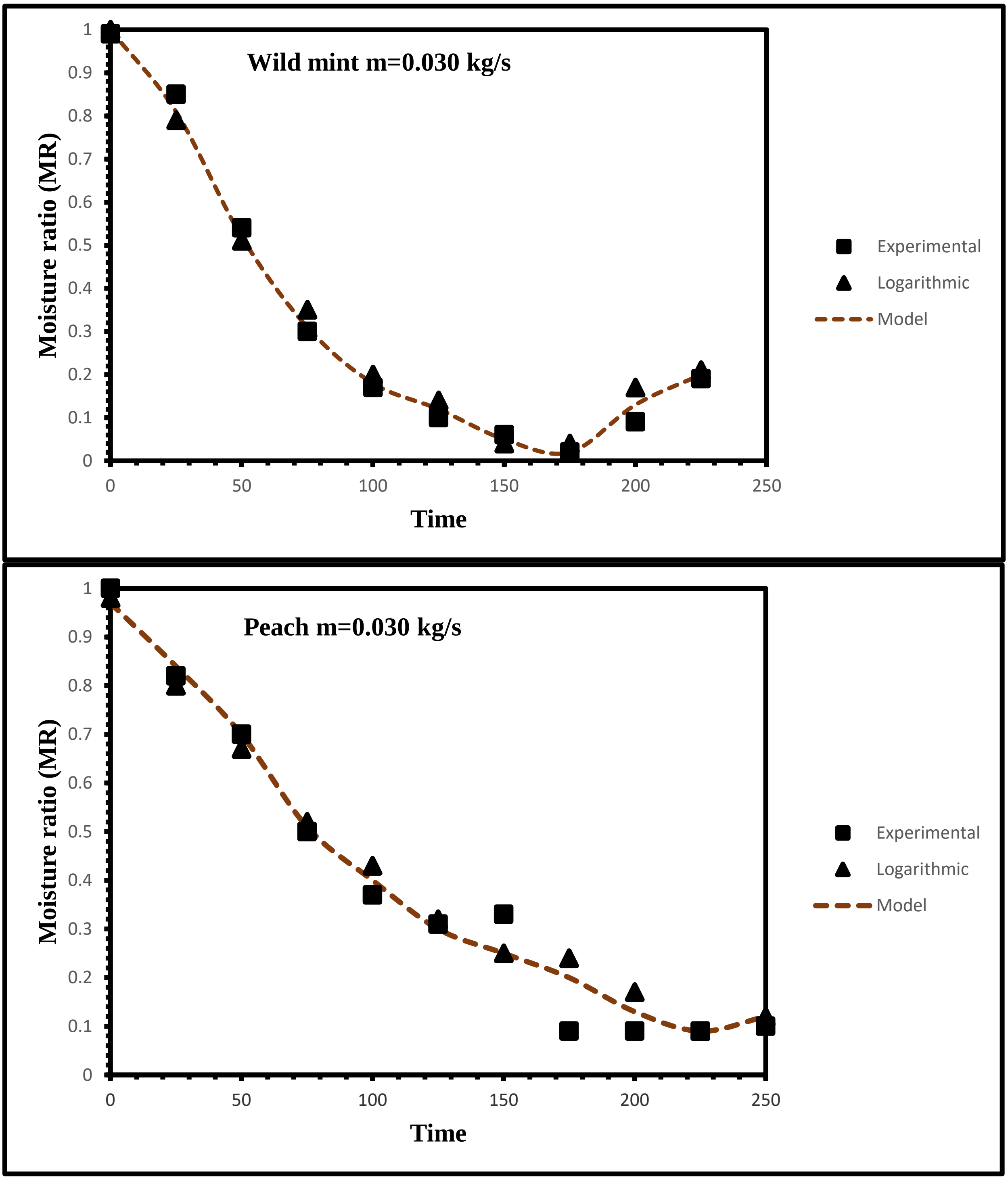


Figure 7. The moisture content calculated using Logarithmic models as well as experimental measurements at a mass flow rate of 0.030 kg/s.

Figure 7 demonstrates that the experimental outcomes were closer to the Logarithmic as well as retrieved models for the majority of the drying period. Moreover, the methodology used in this research agreed well with the experimental data, indicating that our approach may be the finest for explaining the drying characteristics of three products.

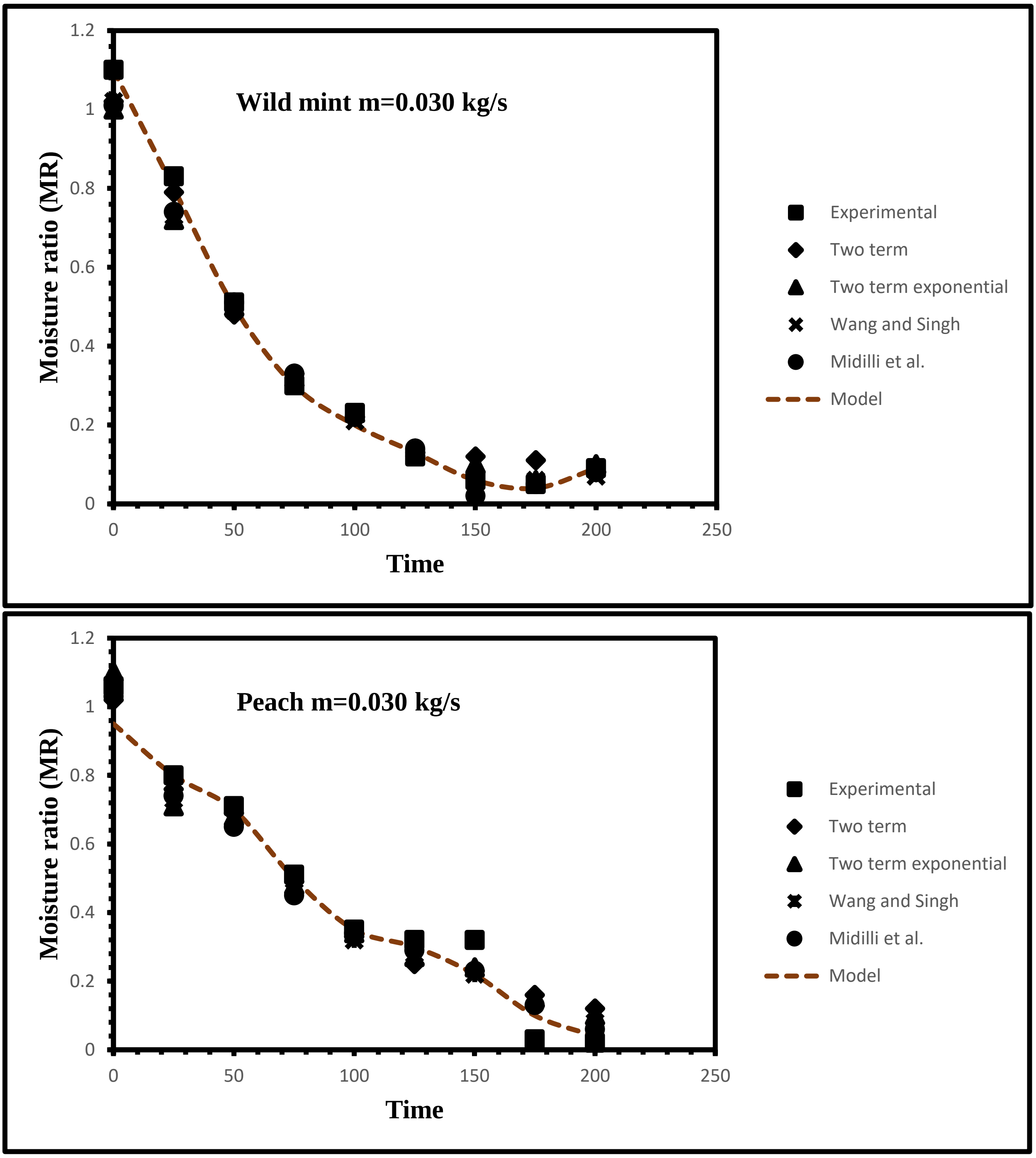


Figure 8. The moisture was determined using the two-term, two-term exponential, Wang and Singh [29], Midilli, et al. [30], prediction model, using experimental data at a mass flow rate of 0.030 kg/s.

5. CONCLUSION

In this research it is easily observed that the most essential parameters controlling the solar drying process, that progressively alter over time. The major objective of this study was to explore and explain the several changes that occur on the essential components from the starting to the completion of the drying process. These components have been seen to interact with one another, such as radiation from the sun, which ultimately affects the mean temperature of the solar collector. The first cause, which was impacted by the temperature of the drying room, dried product was the temperature degrees of the heated air in the intake of the drying room. To compare with the extracted model, the experimental data were fitted to several mathematical moisture ratio models. The proposed moisture content model accurately represents the drying kinetics of the examined products. The RMSE, χ^2 and Sum of Squared Errors SSE errors have the smallest values. The research focuses the massive impact of mass flow rate on drying temperature. Furthermore, the mass flow has an effect on the coefficients and the various models.

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Authors' Contributions: All authors contributed equally to the conception and design of the study.

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