INFRARED DRYING KINETICS OF COATED PEACH SLICES WITH BASIL SEED AND XANTHAN GUMS

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Abstract - The objective of the current work was aimed to estimate the influence of novel edible coatings based on basil seed and xanthan gums, and infrared (IR) radiation power on the drying efficiency of coated peach slices were investigated in an IR dryer system. Moisture ratio data of IR drying of peach slices were fitted to 7 various empirical thin-layer equations. It was found that Page model has the best fit to show the kinetic behavior and acceptably described the IR drying behavior of coated peach slices with the lowest mean square error (MSE), root mean square error (RMSE), mean absolute error (MAE), and standard error (SE) values and the highest correlation coefficient (r) value. The values of MSE, RMSE, MAE, and SE for all experiments were in the ranges of 0.00017-0.00047, 0.013-0.022, 0.011-0.018, and 0.013-0.022, respectively. The average drying time of uncoated peach slices, coated by xanthan gum and coated by basil seed gum were 52.78, 60.00, and 76.22 min, respectively. The average effective moisture diffusivity (D_{eff}) of uncoated and coated peach slices with basil seed and xanthan gums increased from 2.18×10^{-9} m^2/s to 4.56×10^{-9} m^2/s with increasing IR lamp intensity from 150 watts to 375 watts.

Keywords **- Effective moisture diffusivity; Moisture ratio; Page model.**

I. INTRODUCTION

Polysaccharide edible coatings can improve the quality of agricultural products, and efficiency as a low oxygen barrier, lower water vapor barrier; excellent O_2 and CO_2 barrier characteristics, decreasing oxidative reactions in fruits during drying and allowing reducing water loss or controlling water adsorption. They used to food slices before drying is a technique that can increase the nutritional and sensorial attributes of dried products (Garcia *et al.*, 2014; Salehi, 2020a; Satorabi *et al.*, 2021; Silva *et al.*, 2015). Basil (*Ocimum basilicum* L.) is the endemic plant and its seeds have a high content of mucilage (gums) with great and effective attributes that are similar with food grade gums. Basil seed mucilage is a gum extracted from this seed (Zameni *et al.*, 2015). Main characteristics of the basil seed mucilage as a new source of gums have been lately studied by Salehi (2020b).

Fruits and vegetables drying is a commonly used process for improving product safety as it greatly decreases the microbial activity and enzymatic changes during the storage period, hence, increasing the shelf life of the product. One of the best ways to decrease the drying period is to supply heat by infrared (IR) radiation. IR radiation technique has many benefits include higher heat transfer rate, uniform heating, shorter processing time, higher efficiency (80-90%), low energy utilization, low energy costs, and good final yield quality (Aktaş *et al.*, 2017; Salehi, 2020d).

Numerous previous research study of modified mass transfer models has been conducted. Some researchers developed the moisture transfer model based on Fick's diffusion equation to model moisture transfer between hot air and porous feedstock in the drying process. This model can accurately calculate the moisture loss based on the time and position in IR drying. The aim of this study was to investigate the effect of IR drying on the drying kinetics, moisture content (MC) and effective moisture diffusivity (D_{eff}) of coated peach slices with basil seed and xanthan gums.

II. MATERIALS AND METHODS

A. Peach slices preparation

Peaches (*Prunus persica* L.) were harvested in a patch located in Kermanshah, Iran. Slices of peach (5 mm thickness) were prepared with the aid of a cutter and a cylindrical steel-made cutter. The initial MC of the peach slices was 90% (measured at 105°C for 5 h).

B. Basil seeds gum and Xanthan gum

Basil seeds were purchased from a local market in Hamedan, Iran. Basil seeds were soaked in water for 20 minutes at a seed:water proportion of 1:20 at 25°C. The extracted hydrocolloid was separated from the seeds by passing the seeds through an extractor (Bellanzo BFP-1540 Juicer, China) with a rotating disc which scratched the hydrocolloid layer on the seed surface. The initial MC of this gum was 99.4% (Amini *et al.*, 2021).

Xanthan gum (FuFeng, China) was purchased from a laboratory equipment company in Tehran, Iran.

C. Coating of peach slices

Xanthan gum and basil seed mucilage were used to coating of peach slices. A 0.6% (w/w) xanthan gum and basil seed mucilage solutions were prepared at 25°C and then peach slices were immersed for one minute in these solutions.

D. IR drying

The coated peach slices were dried in an infrared dryer (Fig. 1). The distance of peach slices from the IR lamp surface was equal to 10 cm. The effect of IR radiation power at 3 levels 150 watts, 250 watts, and 375 watts, and drying time on drying performance of peach slices were investigated. The mass variation of peach slices was obtained using a digital balance (LutronGM-300p, Taiwan).

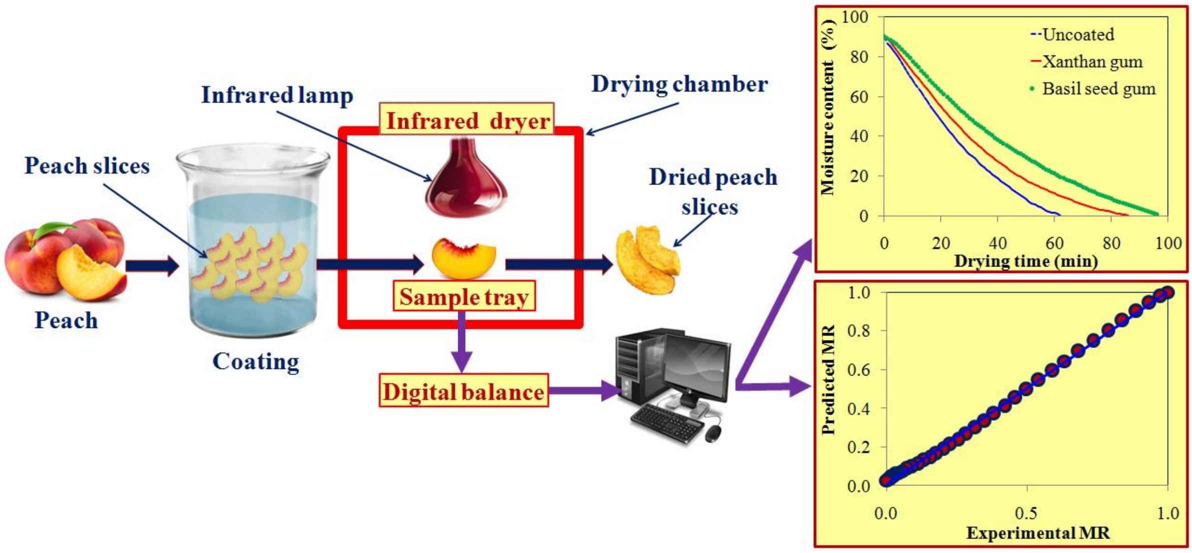

Figure 1. Schematic of edible coating and infrared drying process of peach slices.

E. Drying kinetics

Numerical modeling is one of the appropriate methods for describing the drying kinetics of agricultural products (Salehi, 2020c).

Experimental drying curves of coated peach slices were modeled using the 7 commonly used thin-layer models of Quadratic (Eq. 1), Page (Eq. 2), Newton (Eq. 3), Midilli (Eq. 4), Logarithmic (Eq. 5), Verma (Eq. 6) and Two term (Eq. 7) (Salehi and Kashaninejad, 2018).

$$MR = a + bx + cx^2 \quad (1)$$

$$MR = \exp(-kt^n) \quad (2)$$

$$MR = \exp(-kt) \quad (3)$$

$$MR = a\exp(-kt^n) + bt \quad (4)$$

$$MR = a\exp(-kt) + c \quad (5)$$

$$MR = a\exp(-kt) + (1-a)\exp(-gt) \quad (6)$$

$$MR = a\exp(-k_0t^n) + b\exp(-k_1t) \quad (7)$$

where t and MR are drying time and moisture ratio, respectively. Also, a, b, c, k, n and g are coefficients of models. In these models, the dimensionless moisture ratio was defined as Eq. 8:

$$MR = \frac{M_t - M_e}{M_0 - M_e} \quad (8)$$

where M_t is moisture content of the sample (g water/g dry matter) at time t; M_e and M_0 are balance and primary (fresh slices) moisture content (g water/g dry matter), respectively. In relation 8, since $M_e \ll M_t$ and $M_e \ll M_0$, the value of M_e is insignificant and the relation was facilitated to M_t/M_0 (Salehi *et al.*, 2017).

Curve Expert software (Version 1.34, Hyams, D.G., Microsoft Corporation) was used to calculate and evaluate equations parameters. Mean square error (MSE), root mean square error ($RMSE$), mean absolute error (MAE), standard error (SE), and correlation coefficient (r) values were calculated using Eqs. 9 to 13 to evaluate the accuracy of the fitted models (Bahramparvar *et al.*, 2014). It is noted that the highest r-value (closer to 1) and the lowest MSE, $RMSE$, MAE, and SE values (closer to 0) represent the best model (good fitting).

$$MSE = \frac{\sum_{i=1}^{N}(O_i - T_i)^2}{N} \quad (9)$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N}(O_i - T_i)^2}{N}} \quad (10)$$

$$MAE = \frac{1}{N}\sum_{i=1}^{N}|O_i - T_i| \quad (11)$$

$$SE = \frac{\sigma}{\sqrt{N}} \quad (12)$$

$$r = \sqrt{1 - \frac{\sum_{i=1}^{N}(O_i - T_i)^2}{\sum_{i=1}^{N}(O_i - T_m)^2}} \quad (13)$$

where O_i is the i^{th} experimental data, T_i is the i^{th} predicted data, N is the number of results, σ is the standard deviation, and T_m is calculated by:

$$T_m = \frac{\sum_{i=1}^{N} O_i}{N} \quad (14)$$

F. Moisture Diffusivity (D_{eff})

According to Fick's second law, moisture ratio for different geometries of agricultural products including sphere, slab and cylinder is defined as Eq. 15:

$$\frac{\partial MR}{\partial t} = D_{eff}\nabla^2 MR. \quad (15)$$

Analytical solution of this equation for infinite slab geometry and with assuming a constant moisture distribution, one dimensional moisture, negligible shrinkage, and negligible external resistance used to predict moisture diffusion in samples (Doymaz, 2011; Onwude *et al.*, 2018). The MC values were estimated with the equilibrium MC calculated by dynamic equilibrium data of samples. It is given as Eq. 16:

$$MR = \frac{8}{\pi^2}\sum_{n=1}^{\infty}\frac{1}{(2n+1)^2}\exp\left(-(2n+1)^2\frac{\pi^2 D_{eff} t}{4L^2}\right) \quad (16)$$

where t is the drying time (s), D_{eff} is the effective moisture diffusivity (m^2/s); L is half thickness of peach slices which is equal to 0.25×10^{-2} m in this study.

For a long drying process period, Eq. (16) can be further simplified to:

$$MR = \frac{8}{\pi^2}\exp\left(-\frac{\pi^2 D_{eff} t}{4L^2}\right) \quad (17)$$

Hence, a logarithmic form was introduced as follows:

$$\ln MR = \ln\left(\frac{8}{\pi^2}\right) - \frac{\pi^2 D_{eff} t}{4L^2} \quad (18)$$

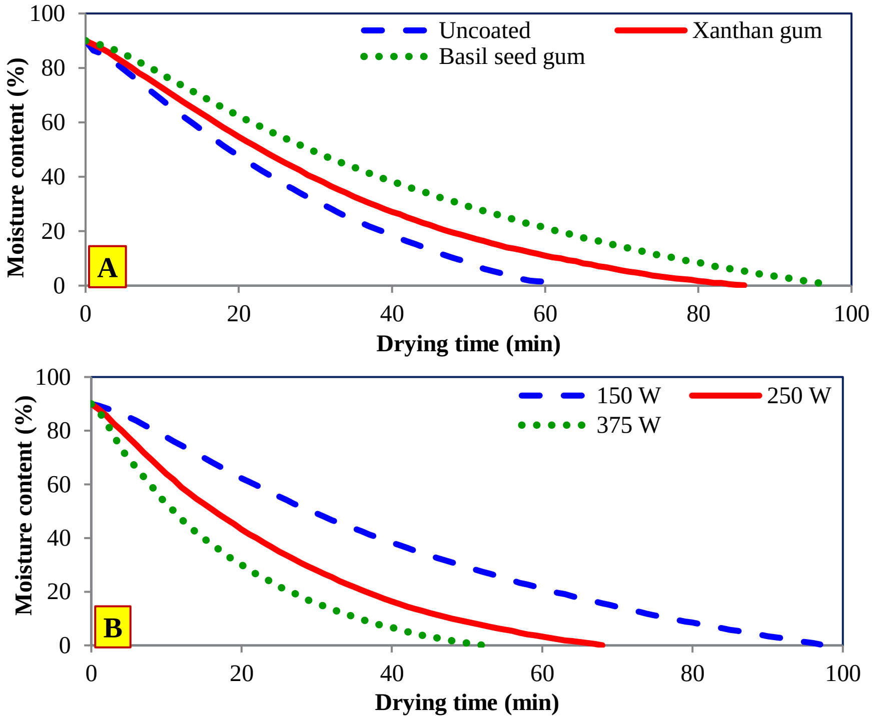

Figure 2. Effect of coating type (A) and infrared power (B) on drying process of coated peach slices.

Table 1- Analysis of variance (ANOVA) results for the effects of the two factors (coating type and power) on the drying time of coated peach slices.

Sources of changes	Degrees of freedom	Sum of squares	Mean square	*F*	*P*
Coating type	2	2510.9	1255.4	22.52	0.000
Power	2	6480.2	3240.1	58.13	0.000
Coating type × Power	4	561.6	140.4	2.52	0.077
Error	18	1003.3	55.7		
Total	26				

The D_{eff} was calculated through Eq. (18) by using the method of slopes. From Eq. 18, a plot of experimental drying data in terms of $\ln MR$ versus time gives a straight line with a $slope(K)$ of:

$$Slope(K = -\frac{\pi^2 D_{eff} t}{4L^2} \qquad (19)$$

III. RESULTS AND DISCUSSION

A. Drying time

Statistical analysis of experimental results (data) demonstrated that the coating type (uncoated, coated by xanthan gum and coated by basil seed gum) and IR power, have a considerable effect on the evolution of drying time of peach slices ($p < 0.01$) (Table 1). The effects of coating type and IR radiation power on the MC (%) of peach slices during drying in the IR dryer are shown in Fig. 2. The average drying time of uncoated peach slices, coated by xanthan gum and coated by basil seed gum were 52.78, 60.00, and 76.22 min, respectively. The average drying times of coated peach slices with basil seed gum were 101.33 min (at 150 W), 72.00 min (at 250 W) and 55.33 min (at 375 W). With increasing IR intensity, due to the increase in air and sample temperature and increasing vapor evaporation rate and reduction in drying time, the specific energy for drying of coated peach slices decreases. The average drying time of coated peach slices with xanthan gum reduced from 84.33 min to 44.67 min when the IR radiation power was increased from 150 watts to 375 watts.

B. Moisture Diffusivity

Influence of IR drying conditions on the D_{eff} of some fruits and vegetables was studied. The D_{eff} values lie within in range of 10^{-8} to 10^{-10} m^2/s for fruits and vegetables in this dryer (Salehi, 2020d). The D_{eff} values are calculated by plotting empirical IR drying data in terms of $\ln MR$ versus time. The values of D_{eff} under different drying conditions of uncoated and coated peach slices calculated by using Eq. 19 and calculated values are shown in Fig. 3. The results of such fitting gave an average regression coefficient of 0.917 indicating that the quality of such fitting was satisfactory. The D_{eff} values of coated peach slices with basil seed gum and xanthan gum were varied from 1.59×10^{-9} to 3.68×10^{-9} m^2/s and 2.16×10^{-9} to 3.85×10^{-9} m^2/s, respectively. D_{eff} values increased with increasing IR power due to higher removal of moisture at higher temperatures (Doymaz, 2011). The average D_{eff} increased from 2.2×10^{-9} m^2/s to 4.6×10^{-9} m^2/s with increasing lamp intensity from 150 W to 375 W. These D_{eff} values are comparable with the reported values of 1.0×10^{-8} to 3.7×10^{-8} m^2/s for dried quince in the

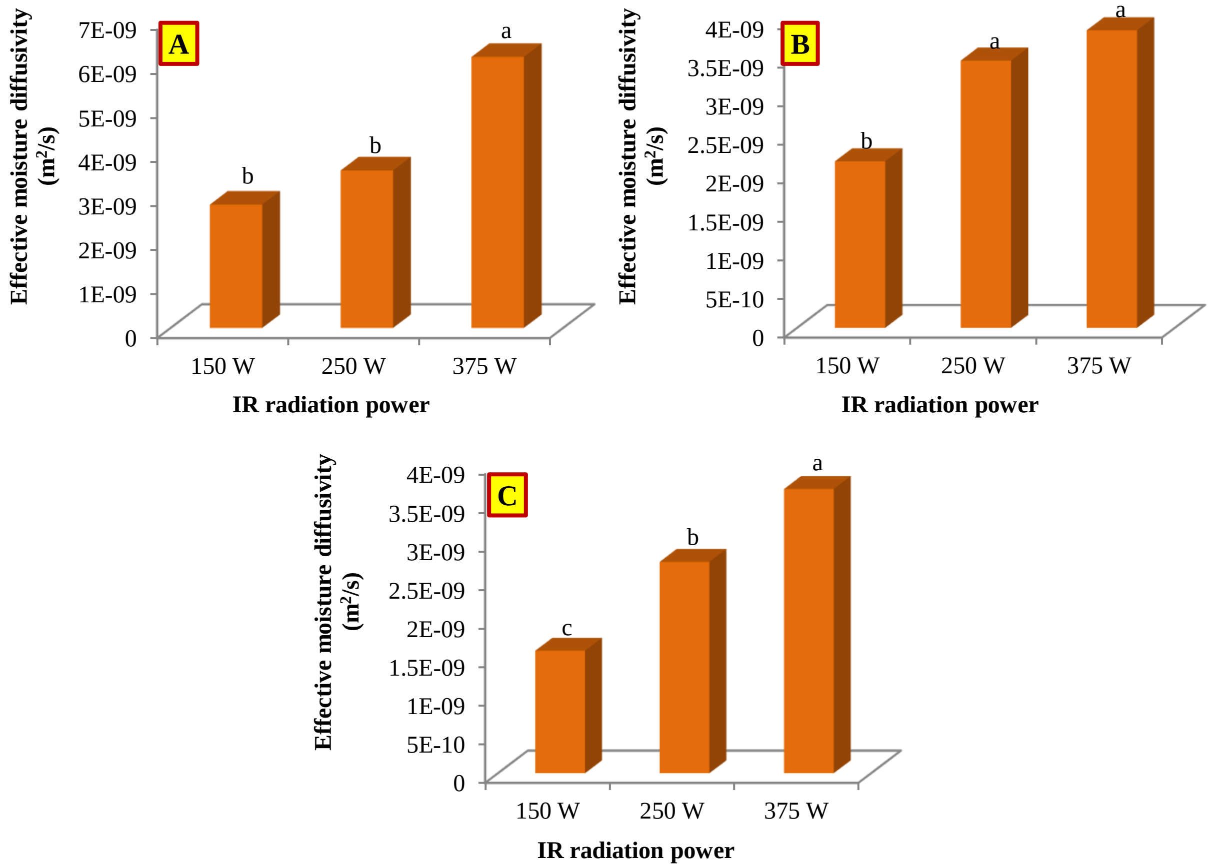

Figure 3. Effective moisture diffusivity values (D_{eff}) of uncoated (A), and coated peach slices with xanthan gum (B) and basil seed gum (C) at different IR radiation power.
* Means with a different letter within columns are significantly different (P<0.05).

IR system (Mehrnia *et al.*, 2017) and 0.87×10^{-9} to 2.6 $\times10^{-9}$ m^2/s for dried pomegranate arils in IR system (Briki *et al.*, 2019).

C. Numerical modeling

To modeling IR drying kinetics of food products, many empirical equations have been applied by researchers. We used 7 thin layer equations (Quadratic, Page, Newton, Midilli, Logarithmic, Verma and Two term) to experimental data to achievement the best equation. The model with the highest correlation coefficient value and the lowest MSE, $RMSE$, MAE and SE values was selected as the best suitable model describing the IR drying processes of uncoated and coated peach slices. The results showed that the model that satisfied these features was the Page model. The fitting drying curves are shown in Fig. 4, and the parameters of fitting drying curves are presented in Table 2. The estimated parameters (fitting data) of the Page model including drying constants, k and n, are tabulated in this table along with corresponding statistical data (MSE, $RMSE$, MAE, SE, and r) for all experiments conditions. The values of MSE, $RMSE$ and MAE for all experiments were in the ranges of 0.00017-0.00047, 0.013-0.022, and 0.011-0.018, respectively. Also, the calculated r and SE values for all data were in the ranges of 0.997-0.999, and 0.013-0.022, respectively. The Page model gave an excellent fit for the describing drying characteristics and prediction of drying time of uncoated and coated peach slices with basil seed and xanthan gums under the various IR drying conditions. This model has been proved for other IR dried products such as apple (Zhu and Pan, 2009), apple pomace (Sun *et al.*, 2007), mushroom (Salehi *et al.*, 2017), and banana (Pekke *et al.*, 2013). The used model allowed the calculation of moisture ratio within the peach slices during IR drying, which would be useful for predicting the accurate drying time.

IV. CONCLUSIONS

Edible coatings can improve the quality of agricultural products, and efficiency as a low oxygen barrier, carbon dioxide, and water vapor, allowing reducing water loss or controlling water adsorption. In this study, the influence of coating with xanthan gum and basil mucilage and IR radiation power on the drying performance of peach slices were studied. The coating type and IR lamp power influenced the drying time of coated peach slices. The average drying times of coated peach slices with basil seed gum were 101.33, 72.00 and 55.33 min at 150 watts, 250 watts and 375 watts, respectively. The D_{eff} values of coated peach slices with basil seed gum and xanthan gum were varied from 1.59×10^{-9} to 3.68×10^{-9} m^2/s and 2.16×10^{-9} to 3.85×10^{-9} m^2/s, respectively. In addition, the average D_{eff} of uncoated and coated peach slices with

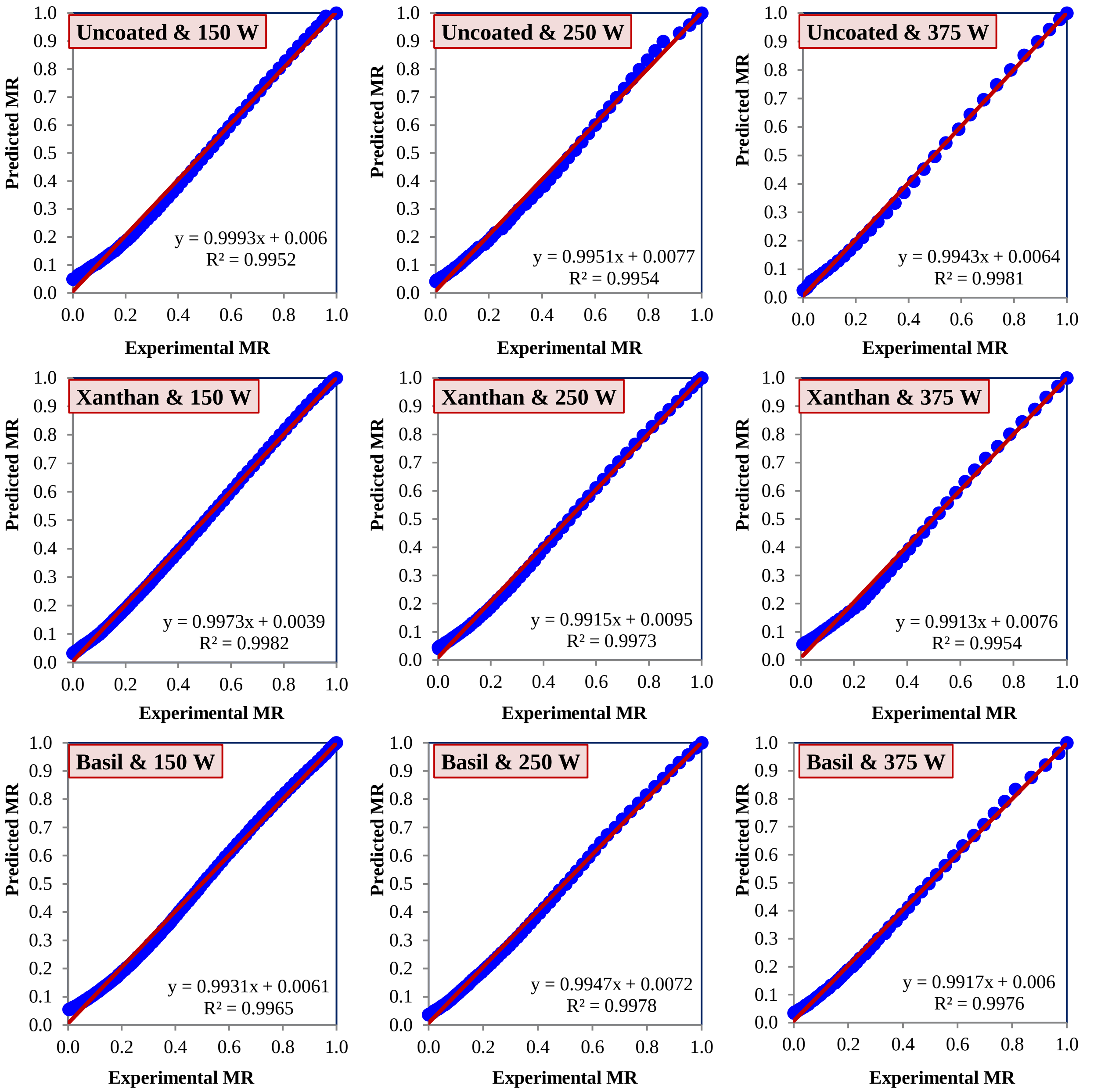

Figure 4. Comparison of estimated data by Page model with experimental data.

Table 2- Model constants of the Page model for all experimental data.

Coating type	Power (W)	*k*	*n*	*MSE*	*RMSE*	*MAE*	*SE*	*r*
	150	0.0111	1.3575	0.00047	0.0216	0.0184	0.022	0.997
Uncoated	250	0.0172	1.3210	0.00045	0.0212	0.0178	0.022	0.997
	375	0.0214	1.4546	0.00021	0.0144	0.0124	0.015	0.999
	150	0.0093	1.3265	0.00017	0.0132	0.0110	0.013	0.999
Xanthan	250	0.0129	1.3809	0.00029	0.0171	0.0136	0.018	0.998
	375	0.0306	1.2312	0.00041	0.0203	0.0168	0.021	0.997
	150	0.0061	1.3483	0.00032	0.0180	0.0145	0.018	0.998
Basil	250	0.0189	1.2246	0.00021	0.0146	0.0120	0.015	0.999
	375	0.0378	1.1376	0.00021	0.0144	0.0119	0.015	0.999

basil seed and xanthan gums increased with increasing IR lamp power. The drying properties were satisfactory characterized by the Page model with the highest r value (greater than 0.997) and the lowest MSE, $RMSE$, MAE, and SE values (a good fit).

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