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The Effect of Gum Based Edible Coating on the Infrared Drying Performance of Apricot Slices

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ABSTRACT: Edible coating applied to fruit slices prior to drying is a technology that can improve the nutritional and sensory qualities of dehydrated products. One of the best ways to reduce the drying time is to provide heat by infrared (IR) radiation. In this study, the effects of polysaccharide based coating (xanthan and Balangu seed gums) on the IR drying kinetics of apricot slices were investigated. In addition, the effects of IR dryer system parameters including IR power (150, 250 and 375 W) and distance of apricot slices from lamp surface (5, 7.5 and 10 cm) on drying time and effective moisture diffusivity (D_{eff}) were investigated. Also, experimental moisture ratio (MR) data were fitted to 7 various empirical thin-layer models (Quadratic, Page, Newton, Midilli, Logarithmic, Verma and Two term). The average drying time of uncoated apricot slices, coated by xanthan gum and coated by Balangu seed gum were 73.11, 81.04 and 83.74 min, respectively. The average effective moisture diffusivity increased from 1.48×10^{-9} m^2/s to 5.56×10^{-9} m^2/s with increasing lamp power from 150 W to 375 W, while it was decreased from 4.28×10^{-9} m^2/s to 2.26×10^{-9} m^2/s with increasing the distance of slices from 5 to 10 cm. The results indicate that Page model is appropriate in describing drying characteristics of apricot slices under the various coating pretreatment and IR drying conditions (r>0.988).

Keywords: *Balangu Seed Gum, Effective Moisture Diffusivity, Moisture Ratio, Xanthan Gum*.

Introduction

Edible coating applied to food slices prior to drying is a technology that can improve the nutritional and sensory qualities of dehydrated products. The edible coatings have been widely studied aiming to increase shelf life of minimally processed products and reduce the solids uptake during osmotic dehydration. Polysaccharide edible coatings present low water vapor barrier; however, they present good gas barrier properties, such as oxygen barrier, and could be used to minimize oxidative reactions in food during drying, pointing out the potential of using edible coatings prior to convective drying, since it could reduce undesirable changes due to large time of exposure of the food to oxygen (Fakhouri *et al.*, 2007; Garcia *et al.*, 2014; Silva *et al.*, 2015; Salehi, 2020a; Satorabi *et al.*, 2021). Garcia *et al.* (2014) reported that edible coating by pectin reduced vitamin C losses during convective drying of papaya slices, when compared to the uncoated samples, showing that the coating protected the samples against the oxidation of this biologically active compound. In addition, coatings differently affected the lightness of the samples during air dehydration, and pectin coating showed the slightest change at this color parameter.

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Balangu (*Lallemantia royleana* L.) is the mucilaginous native plant and its seeds have a high content of mucilage (gums) with outstanding useful characteristics that is comparable with marketable food gums. Balangu seed mucilage is a gum extracted from this seed by using either cold water extraction (Salehi, 2019a, b). Major properties of the Balangu seed gum as a novel source of gum has been recently reported by Salehi (2020b).

Fruits and vegetables drying is a common 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 way to reduce the drying time is to provide heat by infrared (IR) radiation. IR methods could be used as substitution to the current drying methods for producing high-quality dried hydrocolloids. IR heating has many advantages including high heat transfer rate, uniform heating, low processing time, high efficiency (80-90%), lower energy consumption, lower energy costs, and improving final product quality (Salehi, 2020d). In addition, the use of IR dryer in combination with other dryer helped to decrease the drying time by rising the drying rate that leads to reduced energy utilization. Also, symmetrical temperature sharing by IR improved final product quality (Baeghbali *et al.*, 2019).

There is no study available in the literature regarding the effect of infrared drying techniques on the drying kinetics and effective moisture diffusivity (D_{eff}) of coated apricot slices with xanthan and Balangu seed gums. Therefore, the aim of this study was to investigate the effect of gum based edible coating on the IR drying parameters of apricot slices.

Materials and Methods

- *Sample Preparation*

Slices of apricot (5 mm thick), 35 mm in diameter, were prepared with the aid of a cutter and a steel-made cutting tool, which was cylindrical in shape and pointed on one of the sides.

- *Balangu seed gum extraction*

Balangu seeds was physically cleaned and all foreign stuffs were removed. Then, the pure balangu seeds were immersed in water for 20 min at a seed/water relation of 1:20 at 25°C. In the next step, the gum was separated from the inflated seeds by passing the seeds through an extractor (Bellanzo BFP-1540 Juicer, China) with a rotating disc which scratches the mucilage layer on the seed surface. The initial moisture content (MC) of the balangu seed gum was 99.4% (wet basis). Moisture content of samples was determined in a oven at 105°C for 4 h (AOAC, method no. 934.06).

- *Coating of apricot slices*

Xanthan and balangu seed gums were used to coat the fresh apricot slices. A 0.6% (w/w) xanthan and balangu seed gums solution were prepared at 25°C and then apricot slices were immersed for 1 min in a aqueous solution.

- *IR drying*

The coated apricot slices were dried in an IR dryer (IR radiation lamp (NIR), Noor Lamp Company, Iran) (Figure 1). The influence of IR radiation power (at three levels 150, 250 and 375 W), distance of sample from lamp (at three levels 5, 7.5 and 10 cm), and time (min) on drying kinetics of apricot slices was examined. The weight changes of apricot slices were measured by using Lutron GM-300p digital balance (Taiwan, the sensitivity of ±0.01 gr). All measurements were carried out in triplicate order.

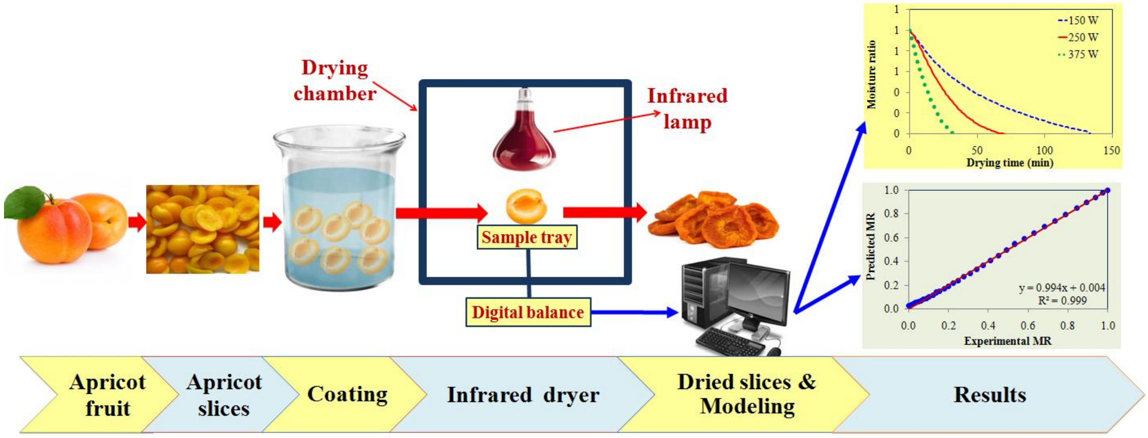


Fig. 1. Schematic of apricot slices drying in an infrared dryer.

- *Drying kinetics modeling*

Numerical modeling is one of the appropriate methods for describing the drying kinetics of food products (Salehi, 2020c). In this study, dimensionless Moisture ratio (MR) were defined as equation 1:

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

Where M_t is MC of the sample (gr water/gr dry matter) at time t; M_e and M_0 are equilibrium and initial MC (gr water/gr dry matter), respectively. In this equation, since $M_e << M_t$ and $M_e << M_0$, the value of M_e is negligible and the equation was simplified to M_t/M_0 (Amini *et al.*, 2021). In addition, to numerical modeling of drying kinetic behavior of apricot slices, 7 commonly used thin-layer models (Quadratic, Page, Newton, Midilli, Logarithmic, Verma and Two term) were used (Salehi & Satorabi, 2021).

Regression analysis was carried out using Curve Expert software (Version 1.34, Hyams, D. G., Microsoft Corporation) to evaluate equations parameters. Correlation coefficient (r) and standard error (SE) were calculated to evaluate the accuracy of models. It is noted that the highest r-value (closer to one) and the lowest SE value (closer to zero) represent the best model (good fitting).

- *Calculation of Moisture Diffusivity (Deff)*

Drying of food products occurs in two periods of constant and falling rates and drying of them controlled by internal diffusion phenomenon. Fick's second law of diffusion can be used to describe the thin layer drying of these products at falling rate. In this study, the D_{eff} values were calculated through equation 2 by using the method of slopes (Salehi & Satorabi, 2021). From this equation, a plot of experimental drying data in terms of lnMR versus time gives a straight line with a slope (K) of:

$$LnMR = Ln(\frac{8}{\pi^2}) - \frac{\pi^2 D_{eff} t}{4L^2} \quad (2)$$

$$Slope(K) = -\frac{\pi^2 D_{eff}}{4L^2} \quad (3)$$

Where MR is the moisture ratio (dimensionless), t is the drying time (s), D_{eff} is the effective moisture diffusivity (m^2/s); L is half-thickness of apricot slices samples.

- *Statistical analysis*

The experimental data were subjected to an analysis of variance (ANOVA) for a completely random design using a statistical analysis system (SAS 9.1 Institute, Inc.). Significant difference between data means were determined using Duncan's multiple range test at P-value<0.05 and it was performed to established the impact of coating type (uncoated, coated by xanthan gum or coated by balangu seed gum), IR radiation power (150, 250 and 375 W), distance of sample from lamp (5, 7.5 and 10 cm) on drying time of apricot slices (P-value<0.05). All measurements were conducted in triplicate.

Results and Discussion

- *Drying time*

Statistical analysis of experimental results (data) demonstrated that the coating type (uncoated, coated by xanthan gum or coated by balangu seed gum) have not a significant effect on the drying time ($p>0.05$) (Table 1), but IR power and samples distance have a significant effect on the drying time of apricot slices ($p<0.01$). The average drying time of uncoated apricot slices, coated by xanthan gum and coated by balangu seed gum were 73.11, 81.04 and 83.74 min, respectively. The average drying time of apricot slices were 128.48, 73.74 and 35.67 min at 150, 250 and 375 W, respectively. With increasing IR intensity, due to the increase in slices temperature and increasing evaporation rate and the decrease in drying time, the specific energy for drying of apricot slices decreases. The average drying time reduced from 101.78 min to 56.07 min when the apricot slices distance were decreased from 10 to 5 cm.

The effects of coating type, IR power and samples distance on the MR of apricot slices are shown in Figure 2. As expected, the MR was decreased with increasing the power because of the increasing temperature and heat transfer gradient between the air and samples. The experimental results are consistent with the literature reports for other products (Toğrul, 2006). Comparing convective and IR heating as means of drying pomegranate arils was studied by Briki *et al.* (2019). The authors reported that the minimum times required to reach 9% moisture (w/w) starting from 78% were 510 and 94 min for convective and IR drying, respectively. In addition, Łechtańska *et al.* (2015) examined the IR assisted hot air drying of green pepper. They reported about 38% decrease in drying time when compared to drying using hot air drying method. In another study, the effect of IR pretreatment on low humidity air drying of apple slices was investigated by Shewale and Hebbar (2017). They observed that the pretreatment with IR waves decreased the drying time approximately 23 and 17% in low-humidity air and hot air drying, respectively.

- *Numerical modeling*

In order to estimate drying kinetics of food products, numerous empirical models have been used by researchers. In this study, 7 thin-layer equations were selected and fitted to experimental data to choose the best and most suitable equation. The model with the highest r and the lowest SE was selected as the best suitable model describing the IR drying processes of apricot slices. The model that satisfied these features was the Page model (equation 4):

$$MR = exp(-kt^{n}) \quad (4)$$

Table 1. Results of analysis of variance for infrared drying time of apricot slices

Sources of changes	Degrees of freedom	Sum of squares	Mean square	P
Coating type	2	1648.1	824.0	0.010
Power	2	117547.0	58773.5	0.000
Distance	2	28221.4	14110.7	0.000
Coating type × Power	4	125.2	31.3	0.941
Coating type × Distance	4	396.5	99.1	0.657
Power × Distance	4	5504.7	1376.2	0.000
Coating type × Power × Distance	8	1166.7	145.8	0.524
Error	54	8763.3	162.3	
Total	80	163372.9		

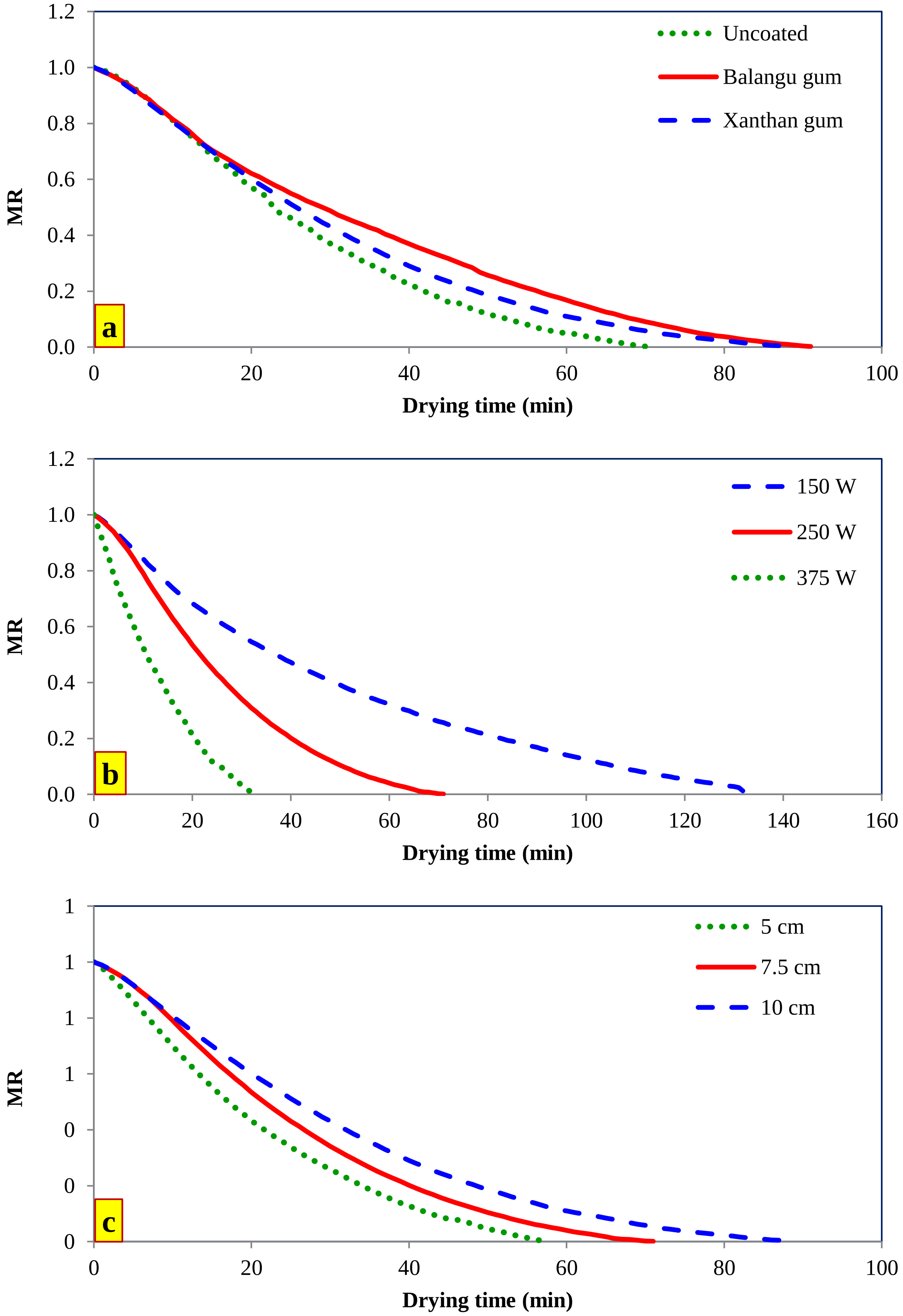


Fig. 2. Variations of moisture ratio with drying time of coated apricot slices at different: a) Coating type (250 W and 10 cm distance); b) IR power (7.5 cm distance, xanthan coating); c) Sample distance (250W, xanthan coating).

Where MR and t are moisture ratio and drying time, respectively. The estimated parameters (fitting data) of the Page model including drying constants, k and n, are tabulated in Table 2 along with corresponding statistical data (r and SE) for all experiments conditions. The values of r and SE for all experiments were in the ranges of 0.988-0.999 and 0.007-0.047, respectively. This model has been proved for other IR dried products such as apple (Zhu & Pan, 2009), apple pomace (Sun *et al.*, 2007), mushroom (Salehi *et al.*, 2017), banana (Pekke *et al.*, 2013) and onion (Sharma *et al.*, 2005).

Figure 3 shows comparison of fitted MR data by Page model with experimental results (250 W, 7.5 cm distance and xanthan coating). These results indicate that Page model is appropriate in describing drying characteristics of apricot slices under the various coating pretreatment and IR drying conditions.

Table 2. Model constants of the Page model for all experiments

Coating type	Power (W)	Distance (cm)	k	n	r	SE
Uncoated	150	5	0.0075	1.366	0.998	0.020
Uncoated	150	7.5	0.0062	1.260	0.996	0.025
Uncoated	150	10	0.0054	1.271	0.999	0.010
Uncoated	250	5	0.0047	1.658	0.998	0.019
Uncoated	250	7.5	0.0097	1.421	0.999	0.007
Uncoated	250	10	0.0068	1.470	0.999	0.011
Uncoated	375	5	0.0659	1.368	0.999	0.013
Uncoated	375	7.5	0.0280	1.549	0.997	0.021
Uncoated	375	10	0.0049	1.702	0.988	0.047
Balangu	150	5	0.0063	1.375	0.996	0.026
Balangu	150	7.5	0.0067	1.309	0.998	0.013
Balangu	150	10	0.0064	1.220	0.999	0.013
Balangu	250	5	0.0128	1.427	0.999	0.014
Balangu	250	7.5	0.0095	1.331	0.999	0.012
Balangu	250	10	0.0091	1.294	0.997	0.024
Balangu	375	5	0.0176	1.672	0.996	0.028
Balangu	375	7.5	0.0237	1.349	0.998	0.017
Balangu	375	10	0.0216	1.255	0.998	0.018
Xanthan	150	5	0.0103	1.329	0.999	0.009
Xanthan	150	7.5	0.0130	1.100	0.998	0.017
Xanthan	150	10	0.0057	1.224	0.997	0.020
Xanthan	250	5	0.0176	1.290	0.999	0.014
Xanthan	250	7.5	0.0087	1.422	0.999	0.010
Xanthan	250	10	0.0090	1.341	0.999	0.010
Xanthan	375	5	0.0576	1.280	0.994	0.030
Xanthan	375	7.5	0.0341	1.282	0.997	0.023
Xanthan	375	10	0.0136	1.381	0.998	0.015

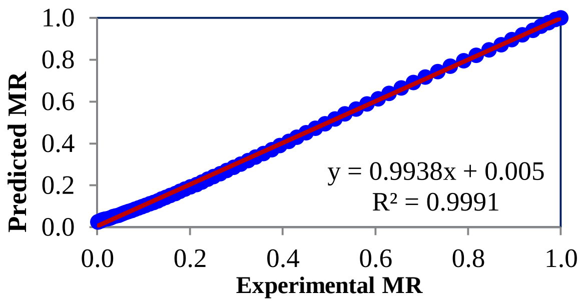
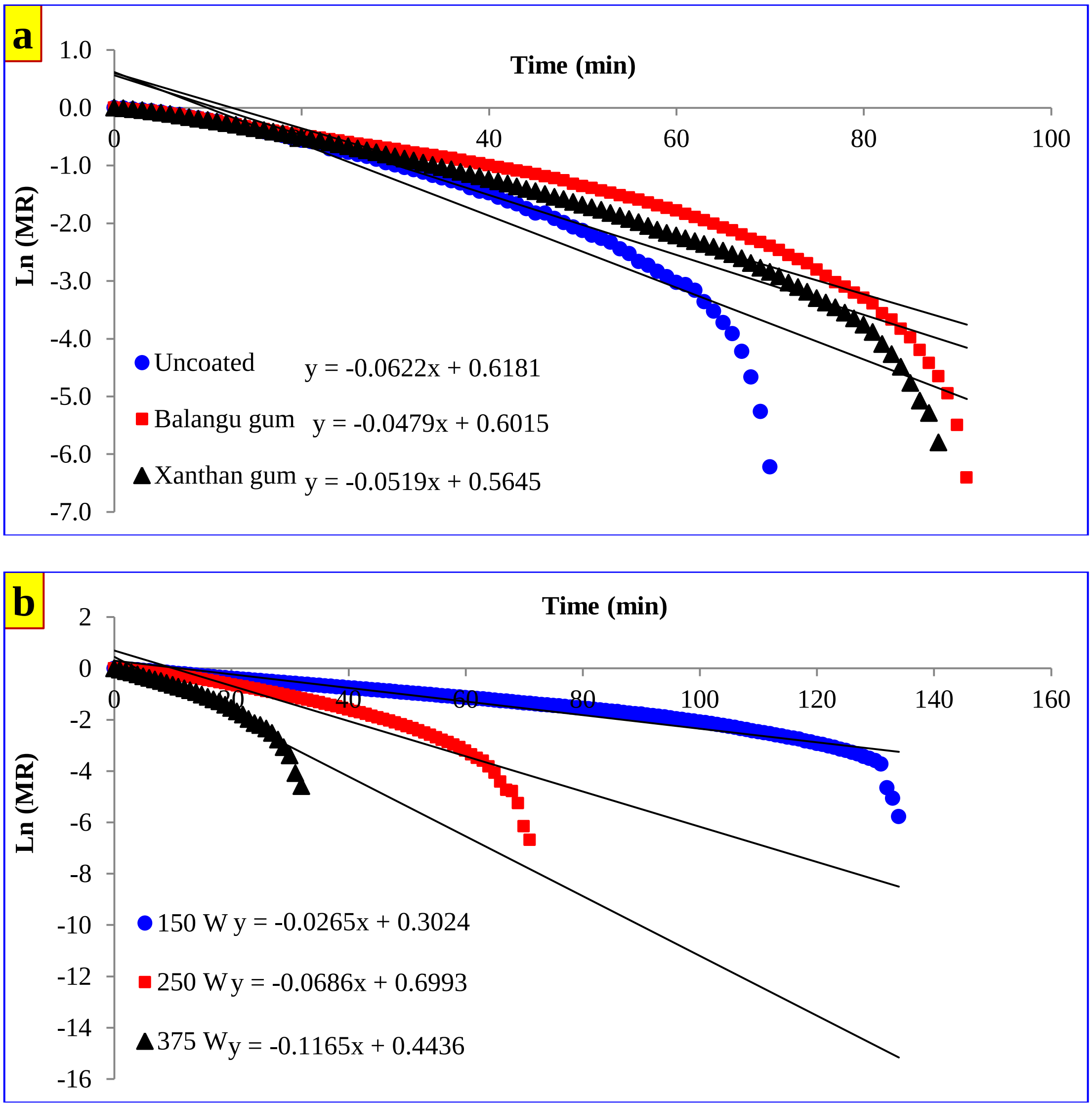


Fig. 3. Comparison of fitted data by Page model with experimental results (250 W, 7.5 cm distance and xanthan coating).

- *Moisture Diffusivity*

The D_{eff} values are determined by plotting experimental drying data in terms of lnMR versus time. The effects of coating pretreatment, IR radiation power and samples distance on the lnMR are shown in Figure 4. The values of D_{eff} at different condition drying of apricot slices obtained by using equation 3 and estimated values are shown in Table 3. The D_{eff} values of apricot slices were ranged from 0.98×10^{-9} and 8.64×10^{-9} m^2/s. D_{eff} values increased with increasing IR radiation power because of the rapid movement of water at high temperatures. Effect of IR drying systems on the D_{eff} of some fruits and vegetables was studied (Salehi, 2020d). The D_{eff} values lie within in range of 10^{-8} to 10^{-10} m^2/s for fruits and vegetables. The average D_{eff} values of apricot slices decreased with increasing slices distance from IR lamp and they were equal 4.28×10^{-9}, 3.17×10^{-9}, and 2.26×10^{-9} m^2/s for 5, 7.5 and 10 cm, respectively. The average D_{eff} values of uncoated apricot slices, coated by xanthan gum and coated by balangu seed gum were 3.63×10^{-9}, 3.11×10^{-9}, and 2.98×10^{-9} m^2/s, respectively. The results of such fitting gave an average regression coefficient of 0.94 indicating that the quality of such fitting was satisfactory.



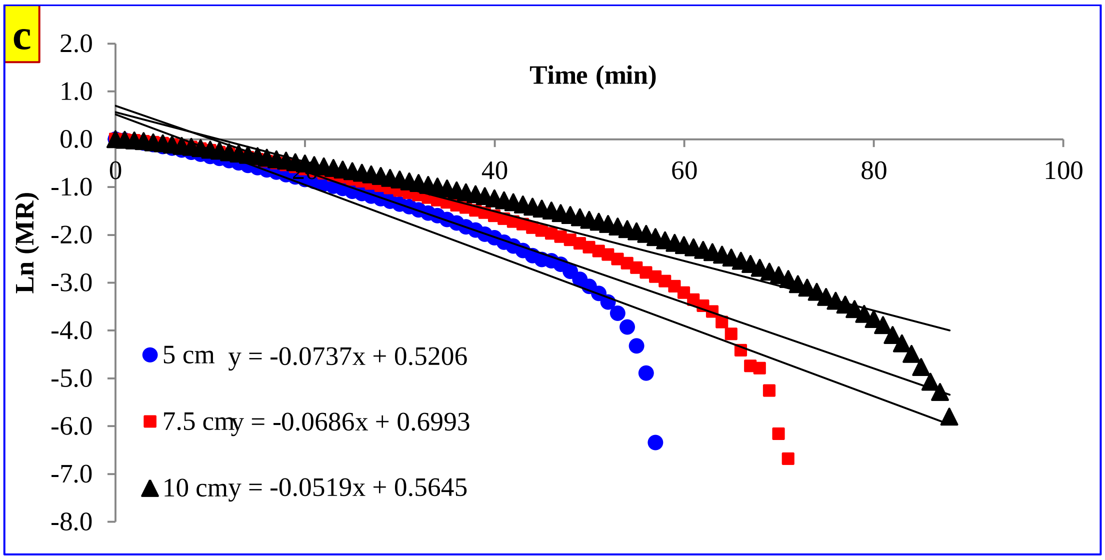


Fig. 4. Variations of the Ln (MR) with drying time of coated apricot slices at different: a) Coating type (250 W and 10 cm distance); b) IR power (7.5 cm distance, xanthan coating); c) Sample distance (250W, xanthan coating).

Table 3. Effective moisture diffusivity values (D_{eff}) of apricot slices at different IR drying conditions

Coating type	Power (W)	Distance (cm)	Effective diffusivity (m^2/s)	r
Uncoated	150	5	2.12×10^{-9}	0.936
Uncoated	150	7.5	1.14×10^{-9}	0.971
Uncoated	150	10	1.05×10^{-9}	0.940
Uncoated	250	5	2.98×10^{-9}	0.948
Uncoated	250	7.5	2.76×10^{-9}	0.976
Uncoated	250	10	2.59×10^{-9}	0.937
Uncoated	375	5	8.64×10^{-9}	0.978
Uncoated	375	7.5	7.37×10^{-9}	0.947
Uncoated	375	10	4.04×10^{-9}	0.884
Balangu	150	5	2.12×10^{-9}	0.911
Balangu	150	7.5	1.53×10^{-9}	0.963
Balangu	150	10	0.99×10^{-9}	0.968
Balangu	250	5	3.56×10^{-9}	0.936
Balangu	250	7.5	2.12×10^{-9}	0.953
Balangu	250	10	2.00×10^{-9}	0.927
Balangu	375	5	6.30×10^{-9}	0.932
Balangu	375	7.5	4.81×10^{-9}	0.887
Balangu	375	10	3.34×10^{-9}	0.947
Xanthan	150	5	2.26×10^{-9}	0.945
Xanthan	150	7.5	1.11×10^{-9}	0.945
Xanthan	150	10	0.98×10^{-9}	0.918
Xanthan	250	5	3.07×10^{-9}	0.930
Xanthan	250	7.5	2.86×10^{-9}	0.932
Xanthan	250	10	2.16×10^{-9}	0.958
Xanthan	375	5	7.49×10^{-9}	0.894
Xanthan	375	7.5	4.85×10^{-9}	0.948
Xanthan	375	10	3.22×10^{-9}	0.932

Conclusion

In this study, the influence of coating pretreatment, IR radiation power (150-375 W) and the distance of slices from IR lamp (5-10 cm), on the drying kinetics and D_{eff} of coated apricot slices by xanthan and balangu seed gums were studied. The coating pretreatment, IR lamp power and distance of slices from lamp influenced the drying time and D_{eff} of apricot slices. The average drying time of apricot slices were 128.48, 73.74 and 35.67 min at 150, 250 and 375 W, respectively. The rate constants of the 7 various empirical kinetic's models for thin layer drying of apricot slices were established by nonlinear regression analysis of the experimental data. It was found that Page model has the best fit to show the kinetic behavior and acceptably described the IR drying behavior of apricot slices with the highest correlation coefficient (r) and the lowest standard error (SE) values. The average D_{eff} values of uncoated apricot slices, coated by xanthan gum and coated by balangu seed gum were 3.63×10^{-9}, 3.11×10^{-9}, and 2.98×10^{-9} m^2/s, respectively. Values for the D_{eff} of apricot slices samples were obtained in the range of 0.98×10^{-9} and 8.64×10^{-9} m^2/s and they were increased with increasing lamp power while decreased with increasing distance of slices from lamp.

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