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TECHNICAL NOTE

Application of Three Types of Dryers Namely Tunnel, Fluidized Bed, and Fluidized Bed with Microwave for Drying of Celery, Corn, and Sour Cherry: Experiments and Modeling

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ABSTRACT

In this paper, water content from celery, corn, and sour cherry was removed through tunnel, fluidized bed, and fluidized bed with microwave dryers. One day before performing the experiments, the fruits were put in a refrigerator and ground into slices with average dimensions of 5×8×8 mm. For each experiment, 40 g of the samples were inserted in dryers. Moisture content in the samples was determined by weighting the samples using a balance. Experiments were accomplished under the air velocity of 1 to 3 m/s, the temperature of 40 to 60 ^{o}C, and the microwave power of 180 to 540 W. Influences of these operating conditions on the drying yield were presented and discussed. This study evidenced that the fluidized bed with microwave field resulted in the highest drying rate among the applied drying methods. The optimum temperature and air velocity for attaining the maximum drying performance were 60 ^{o}C and 1 m/s. In addition, the Exponential and Page's models were used to fit the experimental data. The results showed that Page's model had a good agreement with the experimental data.

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1. INTRODUCTION

Many of vegetables and fruits that are widely used in the cosmetic, pharmaceutical, food, and even chemical industries are produced during particular seasons. Therefore, without essential efforts they can't be available on another time [1]. One of the applicable efforts to preserve vegetables and fruits for an extended period of time is drying that has been largely employed from a long time ago up to present. Drying removes water content from samples to such a degree that enzymatic activity decreases significantly. Therefore, deterioration reactions proceed very slowly [2]. There are many applicable drying methods such as drying by shadow, hot air, superheated steam fluidized bed, vibrating fluidized bed, and microwave [1, 3-6]. Drying by shadow and hot air are two of the oldest drying methods. Although these two methods are low cost, they have several disadvantages like lengthy drying time and low productivity that make them uneconomic in large scale [7, 8]. In the recent years, drying by microwave field and fluidized bed have attracted large attentions [9-12]. Moreno et al. [13] dried forest biomass particles using three types of dryers. They studied the influence of vibration acceleration, rotation velocity of a stirrer, and inert solids mass fraction on the performance of vibro-fluidized bed, agitation-fluidized bed, and fluidized bed with inert solids, respectively. Their results indicated that the agitation-fluidized bed had the highest performance. Using a continuous microwave dryer, wet processed wood fibres were dried by Bartholme et al. [14]. They measured the drying yield and compared it with convective drying method from the total energy consumption point of view. Li et al. [15] introduced a novel method for achieving a high product quality with low energy consumption. They proved that drying performance can be improved by increasing the temperature. Using a microwave dryer, Tahmasebi et al. [16] investigated the effect of various parameters such as microwave output power, particle size, and the weight of samples on the drying performance.

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In spite of many publications in the drying fields [12, 17-20], few efforts are available in literature on the drying of fruits by different methods. So, further experimental data about the drying of various fruits and vegetables are still needed to be developed using different drying methods to overcome these limitations. Using such data, it will be possible to compare the performances of various dryers as well as investigating the influence of operating parameters on the drying duration. The purpose of this paper was to investigate the drying of celery, corn, and sour cherry using tunnel dryer (T.D.), fluidized bed (F.B.), and fluidized bed with microwave dryer (F.B. + MW). The effects of temperature, air velocity, and microwave power on the drying efficiency were determined. Another aim was to evaluate two well-known models to fit the experimental data of celery, corn, and sour cherry.

2. MATERIALS AND METHODS

This section is organized as follows. First in subsection 2.1, the used fruits and vegetables along with their pretreatment process are presented. Then tunnel, fluidized bed, and fluidized bed with microwave dryers are discussed in subsection 2.2. After that, the procedures for performing the experiments are described in subsection 2.3. Finally, the applied mathematical models to correlate the experimental data are explained in subsection 2.4.

2. 1. Materials As mentioned, the used fruits in this paper were celery, corn, and sour cherry. One day prior to each drying experiment, the required fruits were purchased from a fruit store in Sanandaj city of Iran. Then, the samples were placed in nylon packages and stored in a refrigerator at 4 ^oC to prevent the leakage of water from the samples. The samples were taken out of the refrigerator two hours before performing the experiments in order to stabilize with the temperature of lab. After that, they were ground into slices with the average dimensions of 5×8×8 *mm* using a domestic grinder. In order to avoid drying at the time of grounding, the applied cutting board was covered by an impermeable layer.

2.2. Equipment

2. 2. 1. Tunnel Dryer The applied tunnel dryer in this study was made by Armfield company. This dryer, which is revealed in Figure 1, comprises of a dryer chamber with a cross sectional area of 27 cm^2, a fan, a drive motor, an electrical heater, an air distributor, a tray for installing the materials, a digital balance, a control panel, and several measuring sensors. The mechanism of drying by this conventional dryer is discussed as follows. The motor rotates the fan and causes a flow of air in the tunnel chamber. A controller with ten specified levels is used to adjust the fan rotating speed. Air velocity in the drying chamber is measured by a standard-618 speedometer with an accuracy of 0.1 *m/s*. The air passes through the electrical heater to reach the set point temperature. The power of the electrical heater has ten levels. The air temperature in the dryer is measured with a thermocouple with 0.1^oC accuracy that is placed before the tray. Several plastic tubes that are used as distributor are installed after the electrical heater to make a uniform airflow inside the dryer chamber. The airflow passes through the tray, removes the water content of the samples, and subsequently exits from the other side of the dryer chamber to the atmosphere. For measuring the mass of samples during the experiments and calculating the residual water content, the tray is connected to the digital balance (Kern PLS 6200-2A) with an accuracy of 0.01 *g*.

2. 2. 2. Fluidized Bed with Microwave Dryer The set-up of fluidized bed with microwave dryer, made by our research group in the University of Kurdistan, is depicted in Figure 2. The apparatus consists of a domestic microwave oven (LG, MC-2003 TR(S)) with the powers of 180, 360, 540, 720, and 900 *W*, a digital balance, a blower, a heater, a distributor, a digital thermostat with the accuracy of 2 ^oC, a humidity meter, a speedometer, a thermocouple with the accuracy of 0.1 ^oC, a steel chamber, and a Pyrex column with the inner diameter of 9 *cm* and the high of 27 *cm*. The blower with a spiral blade rotates with 3000 *rpm* by a motor with 1.5 *kW* and 50 *Hz* to flow the air inside the dryer. A central mobile lid in the blower together with an installed ball valve is used to regulate the air velocity in dryer. After that, the generated air passes through the heater. The heater is a metal tube with an outer diameter of 10.16 *cm*. Four 1.3 *kW* ceramic elements with an outer diameter of 10 *cm* are installed to the metal tube. In order to prevent heat lost from the electrical elements, the space between the tube and elements is filled with two insulator layers. The warm air then enters to the underside of the distributor and exits from its upper side. The distributor is a Teflon plate with 2 *cm* thickness and an average pore size of 4 *mm* to flow the air inside the Pyrex column uniformly. The Pyrex column is installed inside the domestic microwave oven to hold the samples for drying. On the microwave oven, there is a power switch to adjust its power. In addition, a humidity meter is installed to measure the humidity of exit air from the dryer.

2. 2. 3. Fluidized Bed Dryer Apparatus and procedure of the fluidized bed dryer are exactly the same as the fluidized bed with microwave dryer except that the microwave field source must be turned off.

2. 3. Procedure Before putting the samples into each dryer, it was required to turn on the dryer for 20 *min* to ensure that the desired operating conditions were attained. For each experiment, 40 *g* of the samples was weighed using the digital balance and poured into either the Pyrex column, for the fluidized bed dryer, or the tray, for the tunnel dryer. Micro waves passed through the Pyrex column and absorbed by the samples. Transparency of this column made its content visible for the researchers. The column or the tray was then put into the fluidized bed or tunnel dryer. For the case of tunnel dryer, the digital balance was connected to the tray. Therefore, it monitored the weight of the samples and made it easy to calculate the moisture content in the samples. However, for the case of fluidized bed, the column was periodically taken out from the dryer and weighted using digital balance.

2. 4. Mathematical Models Up to now, many useful models have been proposed for drying process. Exponential, Page, modified quasi-stationary, diffusivity, and variable diffusivity model are some of the well-known models for this purpose.

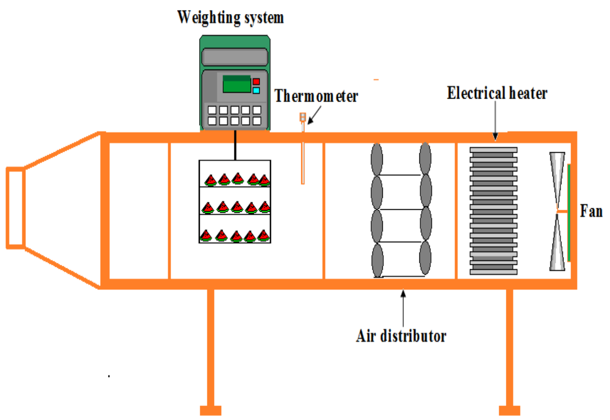

Figure 1. A schematic representation of the tunnel dryer

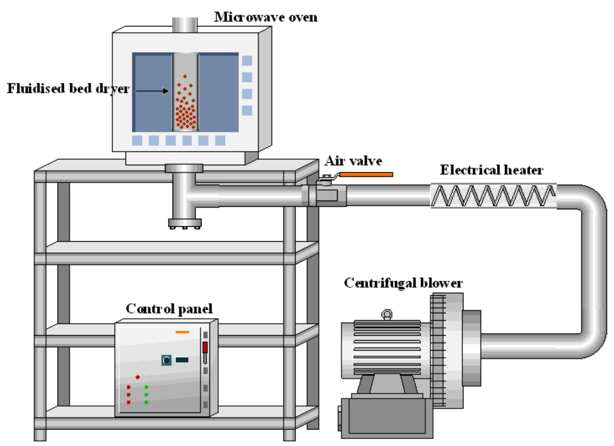

Figure 2. The fluidized bed with microwave dryer

The Exponential model requires only one adjustable parameter, but the others need two parameters for prediction [21, 22]. It was reported that the Page's model has acceptable accuracy and can fit the drying experimental data very well [22]. The experimental data of the current study were evaluated by the Exponential and Page's models. The Page's model relates directly the moisture content to the drying time and is expressed as follows:

$$MR = \exp\left(-kt^{n}\right) \tag{1}$$

where, MR is dimensionless moisture ratio parameter, t is the drying time, k is a rate constant, and n is a dimensionless parameter. MR is defined by the following equation:

$$MR = \left(M_t - M_e\right)/\left(M_i - M_e\right) \tag{2}$$

In this equation, M_t, M_i, and M_e are the moisture content at an arbitrary time, the initial moisture content, and the equilibrium moisture content of the samples, respectively. The initial mass fraction of moisture in celery, corn, and sour cherry was 0.99447, 0.8134, and 0.8097, respectively. According to the literature [22], the equilibrium moisture content is approximately zero in each run due to the high enough drying time. The Exponential model is the same as the Page's model except that the n parameter is equal to unity. The parameters of Exponential and Page's models can be calculated for achieving the best fit of the models to the experimental drying data. These parameters are functions of process variables such as the type of dryer, microwave power, air temperature and velocity, and average particle diameter. In this paper, the prediction ability of these models was assessed with the determination coefficient (R^2) and the root mean square error (RMSE).

3. RESULTS AND DISCUSSION

3. 1. Experimental Drying Data The observation during the drying process showed that the dryer surface was not sticky at all. Additionally, in spite of shrinkage of the material at some operating conditions, there wasn't any change in their color generally. To compare the efficiency of dryers at different operating conditions, Tables 1 reports the values of moisture parameter ratio at fifteenth minutes of drying. Using the reported data in this table, the effects of dryer type, air flow rate, temperature, and microwave power on the required drying time were investigated in the following subsections. The lowers and uppers bound of the operating conditions were chosen according to other drying works available in the literature considering the experimental restrictions. For example, temperature below 40 ^{o}C is very close to the ambient temperature and doesn't have any considerable effect on the drying. On the other side, for the values of temperature more than 60 ^oC, the materials are cooked progressively. Additionally, the microwave power of more than 540 W and the high air velocity lead to burning and throwing away of material, respectively.

3. 1. 1. Effect of Dryer Type Comparison among the performance of dryers can be accomplished according to the experimental results of Table 1. Referring to this table, there were considerable differences between the performances of tunnel dryer with the other methods. In fact, the tunnel dryer resulted the lowest drying rate and needed too much time to reach a standard level of moisture content. For the case of fluidized bed dryer, moisture content decreased sharply and the drying time reduced significantly. Microwave field along with the fluidized bed dryer further improved the drying performance. For example, in the case of celery at 40 ^oC and the air velocity of 1 *m/s*, the attained moisture ratio parameter at fifteenth min was 0.9241, 0.6559, and 0.1730 to 0.4098 for tunnel, fluidized bed, and fluidized bed coupled with the microwave dryers, respectively. In order to be aware of how microwave field improved the drying efficiency, its mechanism is described below with more details. The microwave' fields passed through the Pyrex column, absorbed by the samples, and increased the temperature of samples up to the water boiling point. As a result, the pressure of the interior part of the samples rose up and it consequently forced the water to flow from the center to the surface of samples. .

TABLE 1. The values of MR at 15 min for celery, corn, and sour cherry at various operating conditions.

Run number	Dryer	T (^oC)	v(m/s)	P (w)	MR at 15 min Celery	Corn	Sour cherry
1	F.B+MW	40	1	180	0.4098	0.6634	0.5366
2	F.B+MW	40	1	360	0.2729	0.6541	0.3770
3	F.B+MW	40	1	540	0.1730	0.5339	0.2858
4	F.B	40	1	-	0.6559	0.8695	0.6441
5	T.D	40	1	-	0.9241	0.9573	0.9863
6	F.B+MW	40	2	180	0.5461	0.6696	0.5560
7	F.B+MW	40	2	360	0.3259	0.4917	0.3981
8	F.B+MW	40	2	540	0.2827	0.5122	0.3638
9	F.B	40	2	-	0.6203	0.8333	0.5564
10	T.D	40	2	-	0.9277	0.9438	0.9826
11	F.B+MW	40	3	180	0.4483	0.5525	0.5912
12	F.B+MW	40	3	360	0.3790	0.4254	0.4184
13	F.B+MW	40	3	540	0.2379	0.3470	0.3811
14	F.B	40	3	-	0.5907	0.7746	0.5298
15	T.D	40	3	-	0.8768	0.9349	0.9724
16	F.B+MW	50	1	180	0.4114	0.4428	0.5411
17	F.B+MW	50	1	360	0.2600	0.3746	0.3539
18	F.B+MW	50	1	540	0.2281	0.3292	0.3113
19	F.B	50	1	-	0.5024	0.8014	0.5434
20	T.D	50	1	-	0.9301	0.9306	0.9848
21	F.B+MW	50	2	180	0.4607	0.5549	0.4407
22	F.B+MW	50	2	360	0.2882	0.5374	0.3663
23	F.B+MW	50	2	540	0.2405	0.4564	0.3187
24	F.B	50	2	-	0.5301	0.7674	0.3184
25	T.D	50	2	-	0.9003	0.9217	0.9761
26	F.B+MW	50	3	180	0.4061	0.5735	0.5639
27	F.B+MW	50	3	360	0.2859	0.5471	0.3807
28	F.B+MW	50	3	540	0.2228	0.4855	0.3448
29	F.B	50	3	-	0.5343	0.5080	0.4907
30	T.D	50	3	-	0.8639	0.9147	0.9644
31	F.B+MW	60	1	180	0.2431	0.2962	0.3100
32	F.B+MW	60	1	360	0.1835	0.2858	0.2117
33	F.B+MW	60	1	540	0.0963	0.1927	0.1877
34	F.B	60	1	-	0.4349	0.5225	0.5025
35	T.D	60	1	-	0.9117	0.9252	0.9693
36	F.B+MW	60	2	180	0.2716	0.3466	0.2778
37	F.B+MW	60	2	360	0.2015	0.3288	0.2344
38	F.B+MW	60	2	540	0.1160	0.2276	0.2117
39	F.B	60	2	-	0.3837	0.4991	0.4631
40	T.D	60	2	-	0.8199	0.8829	0.9619
41	F.B+MW	60	3	180	0.1508	0.3556	0.2873
42	F.B+MW	60	3	360	0.2028	0.2299	0.2774
43	F.B+MW	60	3	540	0.0923	0.3110	0.2551
44	F.B	60	3	-	0.2392	0.4645	0.4144
45	T.D	60	3	-	0.7816	0.8965	0.9312

Thus, the moisture content of the samples diminished and the produced water vapors came out gradually. Therefore, unlike tunnel and fluidized bed dryer that liquid water diffused in the samples, for drying with microwave the liquid water first evaporated and then diffused. In view of the fact that diffusion coefficients of gases are quite higher than liquids, the superiority of microwave drying over the other two drying methods can be easily demonstrated. Beside the high drying performance of the microwave dryer, it is very important from product quality point of view to stop the drying process before it causes hot spots on the samples. In fact, at the final time of drying, some points of the samples might be fully dried and microwave field just increases the temperature of samples [23].

3. 1. 2. Effect of Air Velocity The experimental data of Table 1 at the air velocity of 1, 2, and 3 *m/s* indicated that the *MR* parameter for both tunnel and fluidized bed dryers decreased with increasing the air flow rate at constant temperature. The reason for this expected result is due to the drying mechanism of these two dryers that are mainly affected by the mass transfer coefficient. In fact, the higher the air velocity, the higher will be the mass transfer coefficient. The higher the mass transfer coefficient, the higher will be the drying rate and the lower the *MR* parameter. In contrast, air velocity had an opposite effect on the performance of microwave dryer. The reason is that increasing the air velocity increases the heat transfer coefficient. It consequently decreases the temperature of samples promptly. Reducing the temperature decreases the driving force for removing moisture from inner parts of the samples [24]. Despite this opposite effect, the flow of air in microwave dryer shouldn't be stopped and an adequate air flow is always required to exhaust the water vapor from the dryer chamber. Otherwise, the water vapor accumulates in the bed and decreases the concentration driving force for mass transfer operations [23].

3. 1. 3. Effect of Temperature In order to study the effect of temperature on the drying performance, the samples were dried at the fixed temperatures of 40, 50, and 60 ^oC. The results indicated that increasing the temperature enhanced the drying rate. For example, regarding the presented data of sour cherry using fluidized bed dryer at the air velocity of 1 *m/s*, *MR* parameter at fifteenth min and 40 ^oC was 0.6441 while their corresponding values at 50 ^oC and 60 ^oC were 0.5434 and 0.5025, respectively.

3. 1. 4. Effect of Microwave Power The key parameter in microwave dryer is its output power. In this study, the experiments using microwave were accomplished at the powers of 180, 360, and 540 *W*. The obtained results in Table 1 indicate that increasing the microwave power decreased the *MR* parameter. It should be noted that for the drying samples with higher humidity, higher microwave power is required. With higher microwave power, the cost of drying increases directly and it makes the process completely uneconomic. It is the reason why the microwave drying should be used for samples with relatively low moisture content [25]. For samples with high humidity, fluidized bed dryer is the best choice because in spite of the fact that its performance is slightly lower than that of microwave dryer, its operating cost is low and its drying rate is acceptable.

3. 2. Validation of the Applied Models The parameters of Exponential and Page's models together with the statistical parameters of R^2 and RMSE for the case of celery are summarized in Table A1 in the Appendix A. In spite of the fact that the Exponential model has only one adjustable parameter, its prediction ability was comparable with that of the Page's model. For most of the experiments, the value of *n* parameter fluctuated around unity. It clearly indicates that the Exponential model was a good alternative for the Page's model. The values of R^2 and RMSE parameters varied respectively from 0.5324 to 1.0 and 0.0024 to 0.1333 for the Exponent model and from 0.7918 to 1.0 and 0.0026 to 0.0393 for the Page's model. These statistical data proved the superiority of Page over Exponent model. The *k* and *n* parameters in these tables were dependent on the type of the dryers and operating conditions. Based on the results in these tables, the values of *k* for F.B. +MW were more than those of F.B. and T.D., which indicated that the application of microwave led to higher drying rate. To visualize the prediction ability of the Page's model, the drying results at the air velocity of 1 *m/s* and the temperature of 40 ^oC are revealed in Figure 3 to 5. It is worth noting that the drying curves for the other operating conditions had similar trends. In these figures, the points are experimental data and the solid lines are the results of Page's model. Each drying curve can be divided into three subsequent parts including very fast, constant, and falling rate periods [16].

In the first period, drying takes place due to the water evaporation from the surface of samples, but in the falling rate period, internal moisture diffusion controls the process. In general, drying is controlled by the falling rate period where the water diffuses from the internal part of samples to their surface [26]. As can be seen from these figures, there are good agreement between the Page's model and the experimental data. Among the applied drying methods, drying in the presence of microwave power at 540 W, the temperature of 60 ^oC, and the air velocity of 1 *m/s* gave the highest performance.

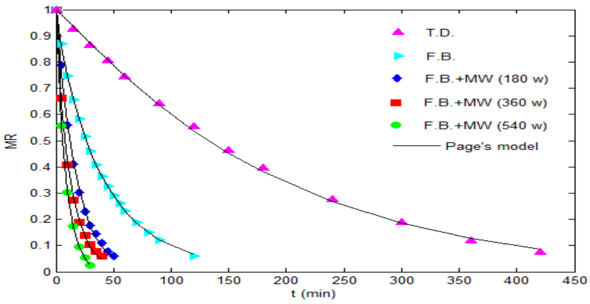

Figure 3. Comparison between the experimental data of moisture ratio parameter and the Page's model for celery at 40 ^{o}C and air velocity of 1 *m/s*.

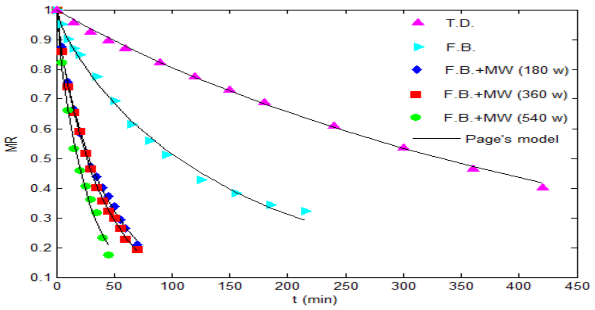

Figure 4. Comparison between the experimental data of moisture ratio parameter and the Page's model for corn at 40 ^{o}C and air velocity of 1 *m/s*.

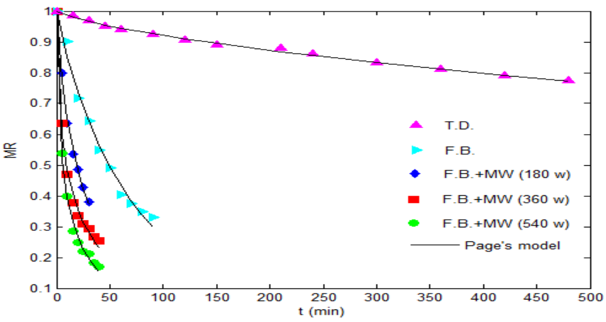

Figure 5. Comparison between the experimental data of moisture ratio parameter and the Page's model for sour cherry at 40 ^{o}C and air velocity of 1 *m/s*.

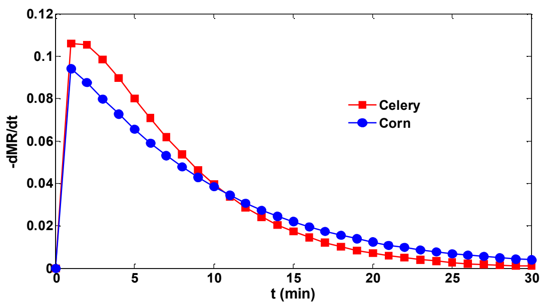

Figure 6. The curves of drying rate at the optimum operating conditions for the drying of celery and corn by microwave dryer

The trends of drying rate at these optimum operating conditions are revealed in Figure 6 for celery and corn. According to this figure, the drying rate rose sharply and after reaching the maximum amount decreased gradually and then leveled off.

4. CONCLUSION

This paper describes experimental and modeling work for drying of celery, corn, and sour cherry. The experiments were designed for achieving the low amounts of water content in the samples using three drying methods namely tunnel, fluidized bed, and fluidized bed with microwave. The main conclusions drawn from this paper are presented as follow:

In the cases of tunnel and fluidized bed dryers, increasing either temperature or air velocity enhanced the performance of drying. For the fluidized bed with microwave, drying rate improved with increasing either temperature or microwave power. However, increasing the air velocity reduced the drying rate and increased the required time for attaining the desirable moisture content. It should be noted that among the applied drying methods, drying in the presence of microwave power gave the highest performance. The optimum temperature and air velocity for maximizing the drying rate were 60°C and 1 *m/s*, respectively. In the final part of this paper, the experimental data were analyzed using two well-known drying models, Exponential and Page's models. The applied models, especially the Page's model, represented the experimental drying data with high accuracy. According to this model, the RMSE parameters for celery, corn, and sour cherry located in the range of 0.0026-0.0393, 0.0042-0.0337, and 0.0027-0.0356, respectively.

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APPENDIX A

In this appendix, the parameters of Exponential and Page's models together with the statistical parameters of R^2 and RMSE for celery are summarized in Table A1.

TABLE A1. The parameters of the Exponential and Page's model together with the values of R^2 and RMSE for the drying of celery at various operating conditions.

Run number	Exponential model k	Exponential model R^2	Exponential model RMSE	Page model k	Page model n	Page model R^2	Page model RMSE
1	0.0575	0.9978	0.0147	0.0535	1.0243	0.9979	0.0149
2	0.0832	0.9967	0.0184	0.1011	0.9274	0.9979	0.0154
3	0.1179	1.0000	0.0024	0.1179	1.0000	1.0000	0.0026
4	0.0253	0.9964	0.0162	0.0353	0.9092	0.9998	0.0041
5	0.0053	0.9964	0.0190	0.0033	1.0937	0.9990	0.0103
6	0.0381	0.9972	0.0149	0.0466	0.9399	0.9985	0.0113
7	0.0721	0.9991	0.0095	0.0813	0.9569	0.9996	0.0067
8	0.0844	0.9989	0.0110	0.0966	0.9487	0.9995	0.0078
9	0.0274	0.9857	0.0301	0.0497	0.8337	0.9993	0.0070
10	0.0053	0.9997	0.0060	0.0045	1.0320	0.9999	0.0028
11	0.0505	0.9979	0.0138	0.0575	0.9586	0.9984	0.0125
12	0.0616	0.9910	0.0280	0.0943	0.8530	0.9984	0.0126
13	0.1016	0.9927	0.0282	0.1548	0.8322	0.9995	0.0080
14	0.0290	0.9837	0.0336	0.0564	0.8150	0.9997	0.0050
15	0.0087	0.9999	0.0038	0.0090	0.9930	0.9999	0.0037
16	0.0593	0.9959	0.0207	0.0415	1.1218	0.9995	0.0078
17	0.0899	0.9997	0.0054	0.0967	0.9718	0.9999	0.0033
18	0.0960	0.9976	0.0173	0.0732	1.1092	0.9998	0.0053
19	0.0456	0.9940	0.0228	0.0479	0.9839	0.9941	0.0238
20	0.0062	0.9940	0.0261	0.0029	1.1519	0.9998	0.0044
21	0.0533	0.9945	0.0234	0.0347	1.1432	0.9997	0.0063
22	0.0814	0.9993	0.0085	0.0798	1.0075	0.9994	0.0093

TABLE A1. Continued

Run number	Exponential model k	Exponential model R^2	Exponential model RMSE	Page model k	Page model n	Page model R^2	Page model RMSE
23	0.0972	0.9995	0.0078	0.1067	0.9624	0.9998	0.0055
24	0.0401	0.9820	0.0382	0.0463	0.9555	0.9827	0.0393
25	0.0082	0.9936	0.0264	0.0042	1.1447	0.9992	0.0098
26	0.0586	0.9991	0.0091	0.0612	0.9854	0.9992	0.0093
27	0.0813	0.9990	0.0105	0.0890	0.9657	0.9993	0.0098
28	0.1008	0.9925	0.0285	0.1550	0.8278	0.9996	0.0070
29	0.0398	0.9861	0.0332	0.0453	0.9600	0.9867	0.0343
30	0.0112	0.9957	0.0228	0.0063	1.1267	0.9995	0.0082
31	0.0952	0.9906	0.0353	0.0546	1.2233	0.9990	0.0130
32	0.1108	0.9980	0.0162	0.0858	1.1072	0.9999	0.0042
33	0.1456	0.9967	0.0222	0.0995	1.1740	0.9998	0.0059
34	0.0622	0.9752	0.0553	0.0206	1.3803	0.9994	0.0094
35	0.0089	0.9790	0.0516	0.0021	1.3086	0.9982	0.0158
36	0.0876	0.9921	0.0315	0.0526	1.2004	0.9995	0.0091
37	0.1062	0.9971	0.0195	0.0796	1.1189	0.9995	0.0088
38	0.1349	0.9971	0.0204	0.0951	1.1560	1.0000	0.0030
39	0.0670	0.9928	0.0283	0.0420	1.1658	0.9987	0.0131
40	0.0121	0.9889	0.0371	0.0054	1.1827	0.9961	0.0232
41	0.1189	0.9939	0.0290	0.0713	1.2163	0.9998	0.0061
42	0.1016	0.9990	0.0110	0.0932	1.0348	0.9992	0.0107
43	0.1535	0.9975	0.0201	0.1155	1.1334	0.9993	0.0118
44	0.0946	0.9954	0.0235	0.0722	1.1053	0.9973	0.0195
45	0.0189	0.9926	0.0308	0.0091	1.1833	0.9989	0.0125

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Application of Three Types of Dryers Namely Tunnel, Fluidized Bed, and Fluidized Bed with Microwave for Drying of Celery, Corn, and Sour Cherry: Experiments and Modeling

TECHNICAL NOTE

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چکیده

در این مقاله، با استفاده از خشک‌کن‌های تونلی، بسترسیالی و بسترسیالی همراه با میکروویو، محتویات آب موجود در کرفس، ذرت و آلبالو خارج‌شده‌است. یک روز قبل از انجام آزمایشها، میوه‌ها در یخچال نگهداشته شدند و به برشهایی به ابعاد $8\times8\times5$ میلیمتر تقسیم شدند. برای هر آزمایش، مقدار ۴۰ گرم از نمونه‌ها در داخل خشک‌کن‌ها قرار گرفت. مقدار رطوبت موجود در نمونه‌ها با توزین آنها توسط یک ترازو تعیین شد. آزمایشها در سرعت هوای بین ۱ تا ۳ متربرثانیه، دمای بین ۴۰ تا ۶۰ درجه سانتیگراد و توان میکوویو ۱۸۰ تا ۵۴۰ وات انجام شدند. تاثیر این پارامترهای عملیاتی بر روی بازده خشک‌شدن ارائه شده و موردبحث قرار گرفت. این مطالعه نشان داد که خشک‌کن بسترسیالی همراه با میکروویو دارای سرعت خشک‌کردن بیشتری نسبت به دیگر روشهای خشک‌کردن است. مقادیر بهینه به‌دست آمده برای دما و سرعت هوا جهت دستیابی به بیشترین بازده خشک‌کردن به‌ترتیب برابر ۶۰ درجه سانتیگراد و ۱ متر برثانیه بود. به‌علاوه، از مدلهای پیج و نمایی جهت برازش داده‌های آزمایشگاهی استفاده‌شد. نتایج نشان داد که مدل پیج دارای تطابق خوبی با داده‌های آزمایشگاهی می‌باشد.

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