INVESTIGATION OF POTATO DRYING KINETICS AND QUALITY PARAMETERS APPLYING ULTRASOUND PRE-TREATMENT

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***Abstract*— In this study, the effect of ultrasound pre-treatment on quality parameters (colour, rehydration, pH and °Brix) of potato samples was investigated. In addition, the drying kinetics of the potato samples was evaluated and ten different thin-layer mathematical models were fitted to experimental data to select the best model for the drying processes. Two different slices of potato samples (2 and 4 mm) were ultrasound pre-treated for 0, 20 and 40 min before drying. Drying was carried out in a modified oven at 60 and 70 °C at an air velocity of 1 m/s. As the ultrasound pre-treatment time applied to the samples increased, the drying time of the product decreased. Drying rate decreased with increasing product slice thickness. When compared to fresh potatoes, a decrease in yellowing values (b*) was observed for the different drying conditions employed. Rehydration ratio values under all conditions ranged from 2.856 to 2.640. Potato samples with a thickness of 4 mm, dried at 60 °C without ultra-sound pre-treatment, presented the highest pH value. The potato samples of 2 mm thick-ness, dried at 70 ° C and treated with ultrasound for 40 min, showed the content of water-soluble solids (°Brix) closest to the fresh product. The results showed that the pre-treatment by ultrasound can be used as an alternative method for drying potato with hot air.**

***Keywords*— Potato, pH, colour, rehydration, ultrasound pre-treatment.**

I. INTRODUCTION

Potato (*Solanum tuberosum* L.) belongs to the Solanaceae family and has around 5000 varieties of potatoes worldwide. The most popular varieties of potatoes that differ in shape, size, starch content, colour and flavor are reported as Russet Burbank, the White Rose and the Katahdin (Zaheer and Akhtar, 2016). The United Nations declared 2008 as the International Year of Potato (UN, 2006). Total potato production in the world for 2017 was 388.190.674 tons (FAO, 2019). Almost half of the potato production was in the Asian continent. China is the main producer country with 99.147.000 tons followed by Indonesia, Russia and Ukraine. The potato is an important dietary product, containing potassium, dietary fiber and vitamin C (Beals, 2019). Potato nutrient values are affected by factors such as production area, soil and climate, agricultural application, preparation and cooking, and type and variety (Wijesinha-Bettoni *et al*., 2019). Dried potatoes, in the form of granules, powder and chips, are used in the formulation of instant soups and sauces (Dehghannya *et al.*, 2018). Potatoes can be dried by different method and have been the subject of many researches (Aprajeeta *et al.*, 2015; Eltawil *et al.*, 2018; Liu *et al.*, 2018). Drying is a process that aims to increase the shelf-life of the product, by reducing its water content (Agrawal and Methekar, 2017). The technique of convective drying with hot air is generally used in industrial processes. Technology development seeks to improve product quality, reducing drying time and energy consumption (Rojas and Augusto, 2018). In the conventional drying method, pre-treatment is being worked on to reduce energy costs and improve product quality. One of these pre-treatment is ultrasound technology. Ultrasonic technology is used in food processing such as extraction, emulsification/homogenization, crystallization, filtration, separation, defoaming, inactivation (enzymatic and microbial), fermentation and heat transfer (Tüfekçi and Özkal, 2015). Ultrasonic technology is used in drying processes as ultrasound assisted drying or pre-treatment in two different ways. During this application, pressure changes occur in the form of contraction and relaxation of the product. This effect is called sponge effect. Due to the effect of contractions, microchannels are formed in the product tissues and these microchannels help the easy exit of the water in the structure. With the accelerated drying process, the products are exposed to heat for less time and thus the quality properties of the products are preserved (Yang *et al.*, 2018). Thus, the objective of this study is to evaluate the drying characteristics of potato slices with different thicknesses (2 and 4 mm), temperatures (60 and 70 °C) and the use of pre-treatment by ultrasound (20 and 40 min). The drying kinetics, color, rehydration ratio, pH and water soluble solids content (°Brix) of the samples were also evaluated.

II. METHODS

A. The Equipment and Procedure for Drying

The experiments were conducted with potatoes (*Solanum tuberosum* L.) purchased at local market (Bursa, Turkey). Potatoes were stored at 4 ± 0.5 °C until the analysis and the drying procedure were carried out. The initial moisture content of the potatoes was measured as 3.69 (g water/g dry matter) on dry basis (d.b.) by drying in the oven at 70 °C for 24 hours.

Before experiment, the products were removed from the refrigerator and allowed to warm to room temperature. For the drying process, mature and undamaged potatoes were chosen. The potatoes were peeled and sliced 2 and 4 mm thick with the aid of a slicer (Börner, Germany). Drying was carried out using a modified oven.

The products were dried at 60 and 70 °C at an air velocity of 1 m/s. The weight losses of the potato samples were determined through the gravimetric method. Samples were withdrawn from the drying oven at regular intervals (10 min) in order to determine their moisture content (d.b.), and were again placed in the oven (Kayisoglu and Ertekin, 2011). The experiments were performed in triplicate.

B. Ultrasonic Application

Ultrasonic bath device with 25Khz frequency and 300W output power was used for the application of ultrasound pre-treatment. Sliced potatoes were placed in a metal basket followed by ultrasound pre-treatment for 20 (US 20) and 40 minutes (US 40) at room temperature. A 1:4 ratio of sliced potatoes distilled water was used in the ultrasonic bath. Control samples were prepared with the same proportion of distilled water. After the ultrasound pre-treatment, the water on samples were removed gently with the help of two-layer filter paper.

C. Mathematical Modeling of Drying Data

Ten mathematical models of thin layer drying were tested to select the best fits to the experimental data of the potato drying process. The models are shown in Table 1.

The moisture ratio (MR) and drying rate (DR) are determined as follows:

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

$$DR = \frac{M_{t+dt} - M_t}{dt} \quad (2)$$

where M_t, M_o, M_e and M_{t+dt} are represented as a moisture content (d.b.) of the product after time t (min), the initial moisture content (d.b.) of the product, the final moisture content (d.b.) and the moisture (d.b.) content at $t + dt$, respectively. In the literature, some researchers have neglected the $M_e$value because it is too small as compared to M_t andM_o. The formula is simplified to the following equation (Gupta *et al.*, 2014).

Table 1. Selected thin layer drying models for convective dried potato slices with pre-treatment by (a) Control; (b) US 20; and (c) US 40.

No	Model name	Model	References
1	Henderson & Pabis	$MR = ae^{-kt}$	Demiray and Tulek (2014)
2	Newton	$MR = e^{-kt}$	Saxena and Dash (2015)
3	Page	$MR = e^{-kt^n}$	Murthy and Manohar (2014)
4	Logarithmic	$MR = ae^{-kt} + c$	Mota *et al.* (2010)
5	Two Term	$MR = ae^{-k_0 t} + be^{-k_1 t}$	Bhattacharya *et al.* (2015)
6	Two Term Exponential	$MR = ae^{-kt} + (1-a)e^{-kat}$	Evin (2011)
7	Wang and Singh	$MR = 1 + at + bt^2$	Arumuganathan *et al.* (2009)
8	Diffusion Approach	$MR = ae^{-kt} + (1-a)e^{-kbt}$	Taşkın *et al.* (2018)
9	Verma *et al.*	$MR = ae^{-kt} + (1-a)e^{-gt}$	Faal *et al.* (2015)
10	Midilli *et al.*	$MR = ae^{-kt^n} + bt$	Midilli *et al.* (2002)

$$MR = \frac{M_t}{M_o} \quad (3)$$

D. Colour Measurement

Fresh and dried potato samples were tested using Hunter Lab Colorimeter (Hunter Lab, USA). Measurements were carried out after the device was calibrated with standard black and white plate. Color measurements were expressed through the Hunter values L^*, a^* and b^* to fresh potato, and L_0^*, a_0^* and b_0^* to dried potatoes. The L^* value, which indicated the lightness measurement, ranged from 0 (black) to 100 (white), the a^* value ranged from -100 (greenness) to +100 (redness), the b^* value ranged from -100 (blueness) to +100 (yellowness). Reading of the colour parameters was performed with 5 replications. Chroma value (C), hue angle (α) and total colour differences (ΔE) values were found by using the following equations (Nevara *et al.*, 2019):

$$C = \sqrt{(a^2 + b^2)} \quad (4)$$

$$\alpha = \tan^{-1}(b/a) \quad (5)$$

$$\Delta E = \sqrt{(L^* - L_o^*)^2 + (a^* - a_o^*)^2 + (b^* - b_o^*)^2} \quad (6)$$

E. Rehydration Ratio

Rehydration was carried out in distilled water at room temperature. Distilled water was added to the dried potato in a 50:1 ratio. After 14 h of contact, the water was removed with the aid of filter paper, and the mass of the hydrated product was measured with an accuracy of 0.001g. The experiments were per-formed in triplicate. The rehydration ratio was calculated using the following equation (Taşkın *et al.*, 2016)

$$R = \frac{M_2 - M_1}{M_1} \quad (7)$$

where M_1 represents the dry product weight M_2 is the product weight after rehydration.

F. Determination of pH Values

The pH measurements of the products were carried out using pH meter (Jenco, USA). The pH measurement of fresh products was made after passing the product through the blender. The pH measurement of the dry products was done after the products were kept in distilled water. This procedure was performed in triplicate.

G. Water Soluble Solid (°Brix)

Digital refractometer (Milwaukee, Romania) was used to deter-mine the soluble solids content of fresh and dried potatoes. For the analysis of fresh product, juice was prepared using a blender. The dried products were kept in pure water and then filtered with the aid of filter paper. The Brix value readings were performed in triplicate.

H. Statistical Analysis

The colour measurement, °Brix, pH, and rehydration ratio results were subjected to analysis of variance (ANOVA) at 95% confidence level (P<0.05), using JMP (Version 7, USA) software. Regression analyses and drying data were carried out to adjust the kinetic models using the MATLAB (2008a, MathWorks Inc., Natick, MA) and MS-Excel (2016) software. The best model was selected according to the highest coefficient of determination (R^2), minimization of the chi-square [χ^2, Eq. 8] and lowest root mean square error [$RMSE$, Eq. 9].

$$\chi^2 = \frac{\sum_{i=1}^{N}(MR_{exp,i} - MR_{pre,i})^2}{N-n} \quad (8)$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N}(MR_{pre,i} - MR_{exp,i})}{N}} \quad (9)$$

where, $MR_{exp,i}$, shows to the experimental moisture content in test number i, $MR_{pre,i}$, , shows to the estimated moisture content, N represents to number of experimental data observed and n presents is the number of independent variables in the model (Kumar *et al*., 2012).

III. RESULTS

A. Drying Kinetics of Potatoes

The change in the moisture content (d.b.) of the product subjected to different drying conditions over time is shown in Fig. 1. With the effect of drying conditions, it was observed that moisture contents decreased over time (Krokida *et al.*, 2003). In addition, it was observed that the drying times varied with temperature, sample thickness and application time of the ultrasound pre-treatment. The drying time of the potato varied from 100 to 250 min. At 70 °C, the pre-treatment with ultrasound for 20 and 40 min allowed a reduction of 7.69% and 15.39%, respectively, in the total time to reach the equilibrium moisture (d.b.) of potato slices with thickness of 2 mm, when compared to the drying process time without pre-treatment. The applied ultrasound pre-treatment eased the exit of the water by disrupting the cell wall structure of the product. Thus, the drying time of the product is reduced (Deng *et al.*, 2019). Fijalkowska *et al*. (2016) found similar results, stating that the drying time of samples submitted to pre-treatment with ultrasound was 13 to 17% shorter when compared to samples without pre-treatment. These results were in parallel with the experiments. The 4 mm potato slices that were not subjected to pre-treatment (control), required 210 and 250 min of drying time, to reach equilibrium moisture (d.b.) at temperatures of 60 and 70 °C, respectively. In all conditions tested, it was found that the drying time of the product decreased with increasing temperature. Similar results were obtained by Ghnimi *et al*. (2017) who reported that the increase in temperature caused a decrease in the drying time of laurel leaves with hot air. The results also showed that the increase in the thickness of the potato slices also caused an increase in the drying time, keeping all other conditions constant. At 70 °C, the final moisture content (d.b.) of a 2 mm potato slice, without pre-treatment, was reached in 130 min. When the thickness increased to 4 mm, the drying time was 210 min. Similar results have been experienced by Sonmete *et al.* (2017) with forced convective drying of carrot samples. The effect of drying temperature was greater than the effect of pre-treatment time at higher drying temperatures (Leeratanarak *et al.*, 2006).

When constant conditions are provided, drying of agricultural products consists of the initial constant rate period such as evaporation of pure water and falling rate periods in which humidity movement is controlled by internal-external resistances (Onwude *et al.*, 2016). Figure 2 shows the drying rate of potato slices as one function of the moisture content (d.b.) of the material, at different temperatures, thicknesses and pre-treatment conditions of the samples. In all drying conditions, the moisture content (d.b.) decreased rapidly in the initial drying stages. In the later stages, the drying rate continued to decrease over time, until it reached equilibrium moisture (d.b.). The drying rate was also influenced by the drying temperature. Similar results were obtained by Torki-Harchegani *et al*. (2015) in drying whole lemon.

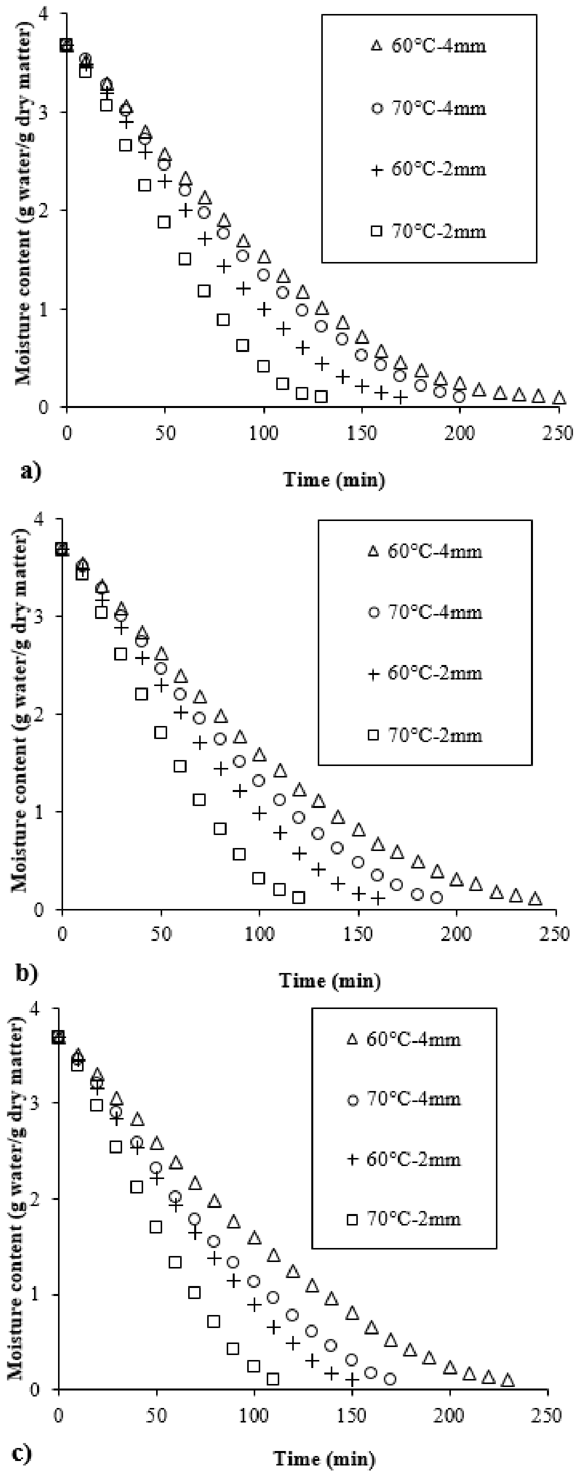

Figure 1: Drying curves for convective dried potato slices with pre-treatment by (a) Control; (b) US 20; and (c) US 40.

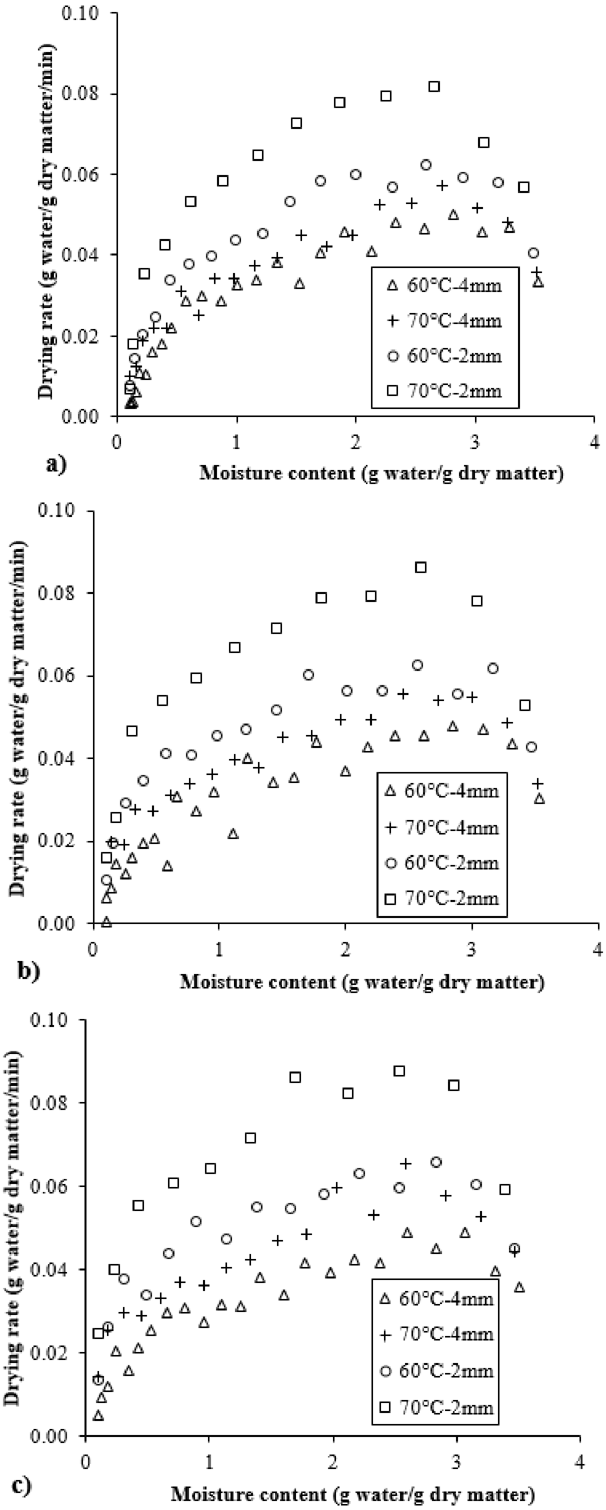

Figure 2: Drying rate changes of potato slices with pre-treatment by (a) Control; (b) US 20; and (c) US 40.

Similar to our result, Beigi (2016) concluded that during the drying of apple slices with hot air, the highest drying rates were obtained when the highest temperatures were used. Meisami-Asl *et al.* (2010), in turn, when studying the application of ultrasound as a pre-treatment for drying apple slices with hot air, found that the highest drying rates were obtained in the samples with less thickness, and submitted to a longer time exposure (40 min). Horuz *et al*. (2017) also obtained similar results when they used pre-treatment by ultrasound in drying tomatoes.

B. Fitting of Drying Curves Potatoes

Fitted mathematical models applied to dried potato slices under different conditions, as well as their respective statistical parameters, are shown in Table 2-4. The results indicate that, in the different drying conditions employed, the values of R^2, *RMSE* and χ^2 varied from 0.9315 to 0.9999; 0.0051 to 0.0841; and 0.1537 x 10^{-4} to 72.2669 x 10^{-4}, respectively. The quality of the fitted models adopted to describe this drying process was based on the highest R^2 and the lowest RMSE and χ^2 values, and, consequently, the Midilli *et al*. model allowed the best fit of the experimental data. The fit of the moisture ratio as a function of the drying time by the model of Midilli et al., in all tested drying conditions, is shown in Fig. 3. Nowacka *et al*. (2012) also found that Midilli *et al*. was the best model to describe the drying kinetics of apple cubes pre-treated by ultrasound.

C. Colour Analysis

The colour parameter plays an important role in the consumer choice of food products. Homogeneous colour distribution on the product indicates the quality of the product and has a significant impact on consumer acceptance (Öztürk *et al.*, 2017). Colour values of fresh and dried potato samples under different conditions are given in Table 5. As can be seen, the L^* values of potato samples vary between 72.564 and 60.652. In addition, no statistical difference ($P > 0.05$) was observed between the L^* values in the samples of potato slices of 4 mm thickness that were dried at 60 °C and pre-treated with 0, 20 and 40 min ultrasound. The increase in a^* values between fresh and dried potatoes was due to the different drying conditions employed. Similar results were observed in the study of drying potatoes by Iyota *et al*. (2001). The dried potato slices presented positive-value chromatic parameter in a^*, thus indicating red shades. There was no statistically significant difference between the a^* values of 2 mm thick samples that were pre-treated with 20-minute ultrasound, and then dried at 60 and 70 °C. According to the results, the b^* values decreased due to the different drying conditions ($P < 0.05$). Similar to our study, Caixeta *et al*. (2002) observed that b^* values decreased with the effect of temperature in the drying of potato. Compared to fresh potatoes, the largest and smallest decrease in the value of b^* was obtained with 2 mm thick, 70 °C and 40 min ultrasound, and with 4 mm thick, 70 °C and 40 min ultrasound, respectively. The lower values of b^* in dry products can be explained by the degradation of chlorophyll and by non-enzymatic reactions during drying. *C* value is accepted as an important indicator of the amount of colour (Izli and Isik, 2015). The highest *C* value was observed in fresh potatoes (P<0.05), and the value of this parameter decreased in all tested drying conditions ($P < 0.05$). Hue angle (a^o) values ranged from 90.537 to 81.620, while *ΔE* values ranged from 31.877 to 18.957.

Table 2. Statistical parameters of thin layer drying models for drying potato slices under different experimental conditions and without pre-treatment (US 0 - control).

No	60ºC-2mm			60ºC-4mm			70ºC-2mm			70ºC-4mm		
	R^2	*RMSE*	$\chi^2(10^{-4})$	R^2	*RMSE*	$\chi^2(10^{-4})$	R^2	*RMSE*	$\chi^2(10^{-4})$	R^2	*RMSE*	$\chi^2(10^{-4})$
1	0.9654	0.0611	37.6704	0.9745	0.05131	25.6329	0.9567	0.0711	49.1318	0.9709	0.0548	28.3457
2	0.9522	0.0719	53.2620	0.9629	0.0619	38.2560	0.9449	0.0801	64.1898	0.9572	0.0665	42.4739
3	0.9980	0.0147	2.4007	0.9981	0.0141	1.8947	0.9975	0.0172	2.6834	0.9976	0.0157	2.5173
4	0.9954	0.0224	3.9049	0.9944	0.0240	3.8094	0.9925	0.0295	6.9410	0.9972	0.0171	1.5463
5	0.9605	0.0654	43.3982	0.9795	0.0460	18.4921	0.9480	0.0779	59.6806	0.9675	0.0580	31.6397
6	0.9492	0.0742	56.6086	0.9614	0.0632	39.8669	0.9403	0.0834	69.5607	0.9549	0.0683	44.7296
7	0.9952	0.0227	5.2790	0.9967	0.0186	3.4642	0.9928	0.0290	8.4322	0.9967	0.0184	2.8393
8	0.9954	0.0224	5.2521	0.9597	0.0645	39.8324	0.9359	0.0865	68.5316	0.9955	0.0215	4.2246
9	0.9933	0.0270	7.4337	0.9927	0.0275	7.6127	0.9902	0.0338	11.4997	0.9952	0.0224	4.3604
10	0.9997	0.0059	0.4423	0.9990	0.0101	0.9990	0.9991	0.0101	0.8759	0.9997	0.0060	0.2432

Table 3. Statistical parameters of thin layer drying models for drying potato slices under different experimental conditions and with pre-treatment (US 20).

No	60ºC-2mm			60ºC-4mm			70ºC-2mm			70ºC-4mm		
	R^2	*RMSE*	$\chi^2(10^{-4})$	R^2	*RMSE*	$\chi^2(10^{-4})$	R^2	*RMSE*	$\chi^2(10^{-4})$	R^2	*RMSE*	$\chi^2(10^{-4})$
1	0.9604	0.0651	42.6076	0.9758	0.0492	23.9976	0.9563	0.0712	51.1911	0.9674	0.0580	28.0553
2	0.9477	0.0749	56.8745	0.9634	0.0606	36.2911	0.9442	0.0805	66.2249	0.9541	0.0688	48.2990
3	0.9960	0.0208	4.4417	0.9983	0.0131	1.8231	0.9974	0.0076	3.3280	0.9968	0.0182	3.2133
4	0.9969	0.0182	2.6529	0.9971	0.0171	1.8436	0.9944	0.0254	4.8888	0.9976	0.0158	1.7042
5	0.9518	0.0719	52.6585	0.9776	0.0473	21.5724	0.9922	0.0300	9.5723	0.9315	0.0841	72.2669
6	0.9442	0.0773	60.6829	0.9618	0.0619	37.8861	0.9391	0.0840	72.0118	0.9515	0.0707	51.0034
7	0.9966	0.0190	3.7410	0.9974	0.0161	2.2945	0.9939	0.0266	7.1624	0.9972	0.0170	2.9874
8	0.9922	0.0290	8.1297	0.9936	0.0253	6.0623	0.9931	0.0283	7.8047	0.9943	0.0243	5.5957
9	0.9956	0.0218	4.9004	0.9954	0.0216	4.2404	0.9922	0.0301	9.0959	0.9960	0.0202	4.1487
10	0.9995	0.0070	0.5556	0.9997	0.0054	0.2354	0.9995	0.0077	0.6703	0.9997	0.0054	0.1869

Table 4. Statistical parameters of thin layer drying models for drying potato slices under different experimental conditions and with pre-treatment (US 40).

No	60ºC-2mm			60ºC-4mm			70ºC-2mm			70ºC-4mm		
	R^2	*RMSE*	$\chi^2(10^{-4})$	R^2	*RMSE*	$\chi^2(10^{-4})$	R^2	*RMSE*	$\chi^2(10^{-4})$	R^2	*RMSE*	$\chi^2(10^{-4})$
1	0.9580	0.0673	44.0763	0.9711	0.0538	29.2627	0.9530	0.0737	52.2787	0.9688	0.0563	32.0586
2	0.9450	0.0770	58.2065	0.9593	0.0638	41.0105	0.942	0.0819	64.7831	0.9575	0.0657	42.8698
3	0.9957	0.0216	5.0965	0.9964	0.0189	3.6269	0.9969	0.0189	4.0438	0.9962	0.0197	3.7924
4	0.9970	0.0180	1.9692	0.9976	0.0156	1.6471	0.9953	0.0232	3.3019	0.9984	0.0129	0.9902
5	0.9910	0.0311	10.1314	0.9798	0.0449	19.9318	0.9509	0.0753	54.6818	0.9356	0.0809	64.9603
6	0.9410	0.0797	62.3819	0.9574	0.0653	42.8921	0.9361	0.0860	71.2852	0.9548	0.0678	45.6035
7	0.9965	0.0195	3.2122	0.9979	0.0144	1.8362	0.9948	0.0246	5.2121	0.9981	0.0138	1.7742
8	0.9914	0.0304	8.9727	0.9945	0.0236	5.4155	0.9920	0.0304	8.4565	0.9930	0.0266	6.4838
9	0.9956	0.0218	4.0779	0.9965	0.0187	3.1718	0.9935	0.0275	6.5590	0.9973	0.0165	2.5818
10	0.9995	0.0071	0.4769	0.9994	0.0079	0.4501	0.9997	0.0055	0.3741	0.9997	0.0051	0.1537

Table 5. Colour values of fresh and dried potato slices at different drying conditions.

Drying conditions	Colour parameters					
	*L**	*a**	*b**	*C*	*α°*	*ΔE*
Fresh	72.564±0.323^{a}	-0.400 ±0.14^{a}	39.368±0.181^{a}	39.370±0.181^{a}	90.537±0.019^{a}	-
US						
60°C-4mm	70.342±0.019^{b}	0.792±0.013^{b}	19.192±0.008^{g}	19.208±0.009^{g}	87.681±0.038^{b}	25.558±0.080^{e}
70°C-4mm	70.548±0.018^{ab}	2.750±0.012^{ı}	23.724±0.015^{d}	23.883±0.016^{d}	83.430±0.028^{f}	21.575±0.013^{g}
60°C-2mm	62.816±0.466^{g}	1.604±0.024^{ef}	22.970±0.467^{d}	23.026±0.467^{d}	86.048±0.082^{cd}	22.467±0.413^{fg}
70°C-2mm	60.652±1.266^{h}	1.708±0.170^{ef}	20.262±0.761^{f}	20.334±0.771^{f}	85.233±0.318^{de}	25.953±1.384^{de}
US20						
60°C-4mm	69.318±0.842^{bcd}	1.540±0.042^{e}	24.938±0.273^{c}	24.986±0.273^{c}	86.510±0.096^{c}	20.001±0.216^{h}
70°C-4mm	70.056±0.325^{b}	0.924±0.009^{bc}	17.586±0.103^{h}	17.610±0.103^{h}	87.036±0.021^{bc}	27.137±0.075^{cd}
60°C-2mm	64.774±0.556^{fg}	2.466±0.055^{h}	16.656±0.318^{hı}	16.838±0.323^{hı}	81.620±0.056^{g}	28.410±0.358^{bc}
70°C-2mm	67.338±1.995^{cde}	2.388±0.224^{h}	16.228±0.884^{ıj}	16.403±0.907^{ı}	81.684±0.330^{g}	28.698±0.863^{b}
US40						
60°C-4mm	69.414±0.653^{bc}	1.006±0.054^{cd}	15.398±0.119^{j}	15.431±0.120^{j}	86.306±0.192^{cd}	29.273±0.083^{b}
70°C-4mm	70.414±1.043^{b}	1.748±0.093^{f}	26.194±0.257^{b}	26.252±0.261^{b}	86.227±0.173^{cd}	18.957±0.092^{h}
60°C-2mm	67.262±0.729^{de}	2.174±0.101^{g}	21.852±0.160^{e}	21.960±0.168^{e}	84.363±0.223^{ef}	23.107±0.159^{f}
70°C-2mm	65.582±0.854^{ef}	1.198±0.491^{d}	12.846±1.372^{k}	12.917±1.320^{k}	84.280±1.028^{ef}	31.877±1.465^{a}

$^{a\text{-}ı}$ Means superscript with different alphabets in the same column differ significantly ($P < 0.05$).

D. Rehydration Ratio

Determination of the rehydration properties of the dried products is often used as the quality parameter. Besides, the rehydration parameter shows the physical and chemical changes affected by the process conditions during drying, the pre-treatment applied to the samples, and the composition of the samples (Doymaz 2014). Rehydration ratio values ranged from 2.640 to 2.856. Statistically (P <0.05), the highest values of the rehydration ratio were obtained in potatoes dried at 60 °C, in the following pre-

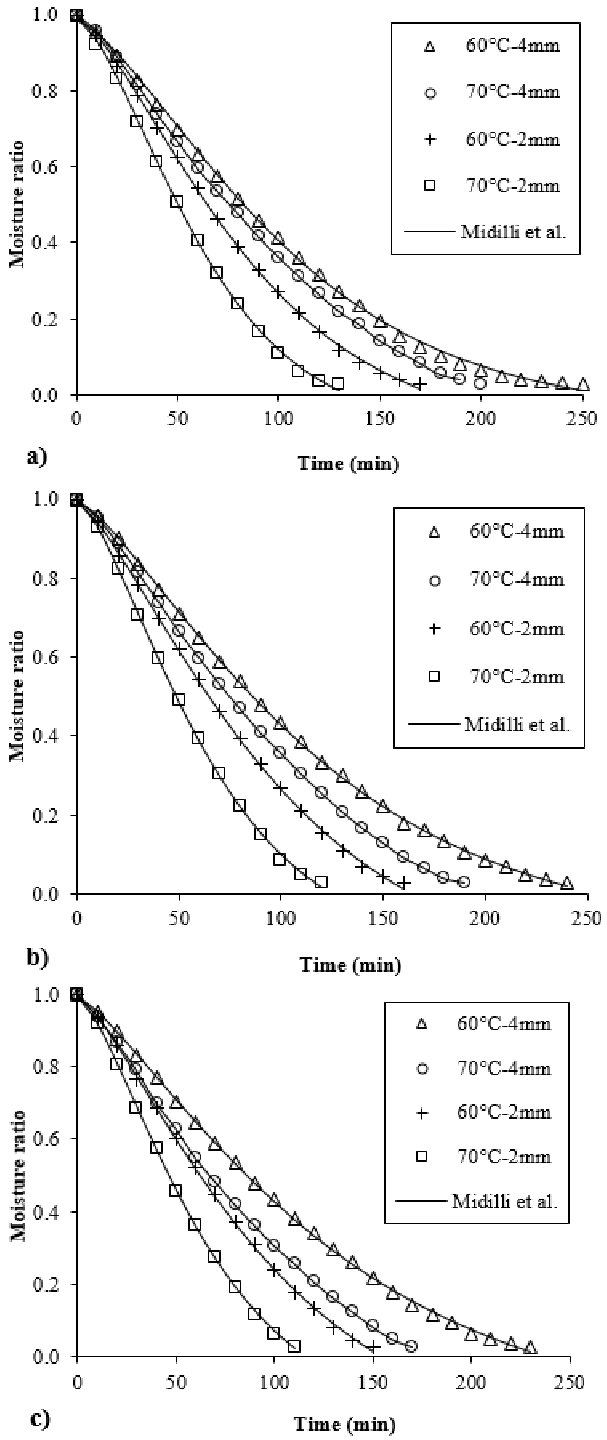

Figure 3: Comparison of the best model to experimental moisture ratios of potato slices with pre-treatment by (a) Control; (b) US 20; and (c) US 40.

treatment conditions and sample thickness: US 40 and 4 mm; US 20 and 4 mm; and US 40 and 2 mm. The results also showed that in the samples dried at 70 °C, the effect of the pre-treatment (US 0, US 20 and US 40) was statistically significant for the ratio of rehydration (P<0.05) in the thickness of 2 mm, but it was not (P>0.05) for the thickness of 4 mm.

E. pH Values

The pH values obtained as a result of drying the potato samples which were pre-treated at different times with different temperature and slice thickness are shown in Fig. 5. It was observed that pH values ranged between 6.020 and 6.635. In addition, a statistically significant difference was found for the pH of fresh and dried potatoes (P<0.05). Similar to our study, Vega-Gálvez *et al.* (2009) examined the pH change caused by drying red capya pepper, and reported that pH values increased after drying. When the effect of ultrasound pre-treatment was examined, a statistical difference was observed between the pH values of all potato samples 4 mm thick, dried at 60 and 70 °C (P<0.05). The highest pH value was obtained in 4 mm thick potato samples, dried at 60 °C, without the use of pre-treatment. According to Zhang *et al.* (2016), pre-treatment by ultrasound can deform cell walls and damage tissues associated with dehydration in the drying process.

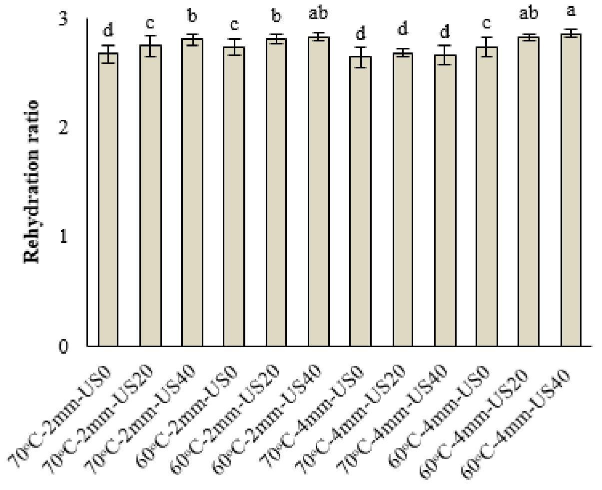

Figure 4: Rehydration ratio values of dried potato slices at different drying conditions.

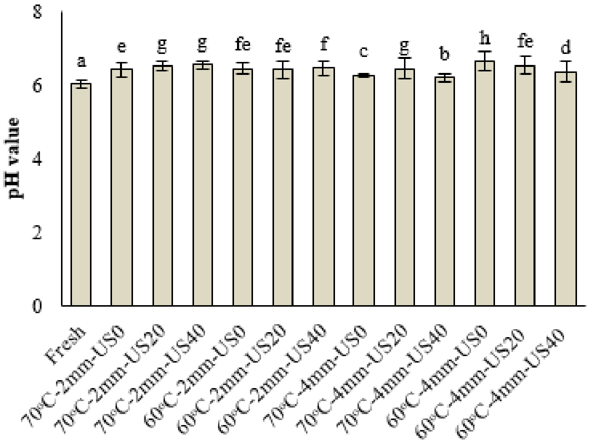

Figure 5: pH values of fresh and dried potato slices at different drying conditions.

F. Water Soluble Solid (°Brix)

The values of the water soluble solids content (°Brix) of the fresh and dried potato samples, under different conditions, are shown in Fig. 6. The values found varied between 4.87 (fresh potato) and 21.0 °Brix (4 mm thick potato slice, pre-treated with US 40 and dried at 70 °C). It was found that the increase in °Brix values occurred due to the drying process (P<0.05). Uslu (2015) obtained similar results in the kumquat drying study. Gilsenan *et al.*

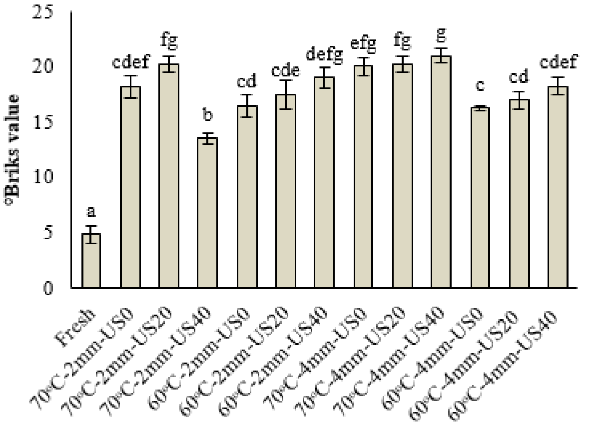

Figure 6: °Brix values of fresh and dried potato slices at different drying conditions.

(2010) found that the content of soluble solids in fresh organic and traditional potatoes was 4.1 and 4.2 °Brix, respectively, which was lower than that found in our study. This may be due to cultivation conditions, type, genetic factors, harvest time and soil structure (Polat *et al.*, 2019).

IV. CONCLUSIONS

The effect of ultrasound pre-treatment on drying potato samples at different temperatures and thick-nesses of the slice was investigated. The experimental data obtained from drying kinetics were adjusted by ten thin layer drying models, widely used in food. The drying time of the potato samples varied from 110 to 250 min, depending on the drying conditions employed. Increasing the ultrasound pre-treatment time reduced the drying time of the product. The drying rate of the products increased with increasing temperature. The statistical parameters used for selection showed that the model by Midilli et al. was the most suitable to describe the drying kinetics of potatoes. The samples with a thickness of 4 mm, pre-treated for 40 minutes and dried at 70 °C, had the Chroma (C) value, which expresses the color intensity of samples closest to that obtained for the fresh product. The increase in the pre-treatment time by ultrasound, of the potato slices 2 mm thick and dried at 70 °C, increased the rehydration ratio values. The pH values and soluble solids content (°Brix) of the dry potato samples were higher than those of the fresh potato samples. The use of a pre-treatment step employing ultrasound, proved to be used to reduce energy costs and improve product quality in conventional drying of potatoes.

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