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EFFECT OF PRE-TREATMENTS ASSISTED MICROWAVE DRYING ON KINETICS AND ENERGY ASPECTS OF DRAGON FRUIT

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Abstract
Drying is one of the most effective preservation methods applied to increase the shelf life of agricultural products. In this study, the effect of different pre-treatments on drying dragon fruit with a microwave was investigated. It is also aimed to determine the drying method with the minimum energy consumption. Dragon fruit slices were dried by microwave at 300 W output power in four different pretreatments as ultrasound, gum arabic, sucrose, and without pretreatment. Pretreatment applications were carried out by performing ultrasound for 10 minutes on dragon fruit slices and soaking them in 10% gum arabic and sucrose solutions before drying. Results showed that the shortest and longest drying times were measured in gum arabic and without pretreatment, respectively. Time-dependent estimation data were calculated by six different thin-layer drying models, considering the drying times and moisture rates. Jena&Das model showed the best fitting performance. As a result, it has been determined that pretreatment applications reduce drying time and energy consumption. In addition, gum arabic pre-treatment is advantageous in terms of energy consumption in microwave drying of dragon fruit.

Keywords: Dragon fruit, drying, modeling, energy, pre-treatment,

1. INTRODUCTION

Dragon fruit (Hylocereus), belong to the cactus family, is a tropical fruit with red or white flesh and small black seeds. It is known to be native to Mexico, North, Central and South America (Yong et al., 2018; Morillo et al., 2022). Many kinds of foods are made from the fruit part of the dragon fruit, or a soft drink is obtained by squeezing the juice (Nurani and Sulistyoningsih, 2021). It is also used as a colorant with other food products (Attar et al., 2022). Dragon fruit is rich in riboflavin, niacin, thiamine vitamins and phosphorus (P), potassium (K), calcium (Ca), iron (Fe), minerals and polyphenol, betalain, anthocyanin. In addition, the steroid content is high, which strengthens immunity, reduces stress, and increases kidney function (Sari et al., 2021). Dragon fruit protects against infectious diseases, prevents cancer, regulates blood sugar, strengthens the digestive system and improves respiratory tract diseases (Nur Izalin et al., 2016; Prisa, 2022).

Fresh fruits and vegetables deteriorate in a short time due to the intense moisture they contain shortly after harvest (Morad et al., 2017). In order to prevent this and increase the shelf life of the products, the drying technique is widely used (Adeleye et al., 2020). Drying is the simultaneous transfer of heat and mass. The high moisture content in the structure of the products is reduced to a value where the microorganism activity ceases (Günaydın et al., 2022). Drying process limits the

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growth of microorganisms, dried products; It becomes more concentrated in terms of macro and micronutrients. In addition, the storage and transportation of products that shrink in volume are easier and cheaper (Kapetanakou et al., 2019). In the microwave drying method, the water molecules in the products are vibrated at high frequency through the magnetron, and the motion energy generated because of this vibration movement is converted into heat energy, and the products are dried from the inside out with its own internal energy (Çetin, 2021). In drying, thermal, and non-thermal pretreatment applications are widely used in order to reduce the processing time and related energy consumption and to maintain the quality parameters of the products at the optimum level (Mirzaei-Baktash et al., 2022). In addition, pre-treatment applications are seen as an important step that accelerates the enzyme inactivation of the products and the cessation of microorganism activity (Jahanbakhski et al., 2021).
The aim of this study; i) drying of purple and white dragon fruits with 300 W microwave without pretreatment (control) and with ultrasound, gum arabic and sucrose pretreatment in four different treats, ii) determining the effect of different pretreatments on color, rehydration capacity, drying time, and energy consumption of dried products.

2. MATERIALS AND METHODS

2.1. Materials

Two different types of dragon fruit as white and purple, were supplied from a greenhouse produced in Gazipaşa district of Antalya. Fresh products were brought to the drying laboratory in the portable type of refrigerator in order to prevent moisture loss and were kept in the refrigerator of +4 ° C during the drying period.

2.2. Methods

2.2.1. Drying Processes

After washing the fruits to be dried and the similar ones were selected, 60.00 ± 0.05 g were weighed for each replication. After the fruits were sliced at a thickness of 1.5 mm, microwave drying operations were carried out in four different treats: 300 W microwave drying with control (without pretreatment), gum arabic, sucrose and ultrasound. During the drying time of the products, weight reduction was measured with the help of a 0.001 sensitive precision scales (Ohaus Adventurer Ax224, Australia) every 5 minutes. The study was conducted in 3 replications. In order to determine the initial moisture content of the dragon fruit, the products were kept in the oven for 48 hours at a temperature of 70 °C (Memmert UN55, Germany). The moisture content of the material before and after the studies were calculated by using the following equation (Eq.1), respectively (Yağcıoğlu 1999).

$$M_0 = \frac{(W_0 - W_d)}{W_d} = \frac{W_w}{W_d} \quad (1)$$

Where: M_0 is moisture content of the samples (kg water. kg drymatter^{-1}); W_0 is the initial weight of the samples (kg); W_d is final weight of the samples (kg) and W_w is wet weight of the samples (kg).

2.2.2. Pre-treatments

Pre-treatment applications, dragon fruit slices before drying; It was carried out by keeping it in 10% gum arabic and 10% sucrose solution for 10 minutes in ultrasound application. In the pre-

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treatments, the ratio of product amount and distilled water was adjusted to be 1:4 (Adiamo et al., 2019).

2.2.3. Modeling

Considering the drying time and moisture ratios of dragon fruit, time-dependent estimation data were calculated by means of six different thin layer drying models previously defined in the literature, and the estimation model that gave the closest results to the experimental data was determined.

2.2.4. Moisture Ratio

The moisture ratio (MR) of apple slices during thin-layer drying was calculated with the use of Eq. (2) (Yağcıoğlu 1999).

$$MR = \frac{M_t - M_e}{M_0 - M_e} \quad (2)$$

Where MR is moisture content, M_e is moisture content at equilibrium (g water. g dry matter^{-1}), M_o is initial moisture content (g water. g dry matter^{-1}).

2.2.5. Rehydration Capacity

The rehydration capacity was calculated by weighing 3 g of dried fruits and keeping them in 100 mL of distilled water at room temperature for 8 hours (Karaaslan et al., 2016).

$$RR = \frac{m_2}{m_1} \quad (3)$$

Where; m_1 and m_2 are the weights of the products before and after drying, respectively.

Figure 1. Determination of rehydration capacity

2.2.6. Color measurements

A hand-held colorimeter (PCE-CSM 5 PCE Instruments, Germany) was used to determine the color characteristics of fresh and dried dragon fruites. Measurements were made in the CIELab color space, and color measurements were performed with 15 replications for each trial.
Chroma (C), and total color change (ΔE) of the products from CIE-L*, a* and b* values were calculated using the following formulas (Eq.4 and Eq.5) (Maskan, 2001);

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

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The total color change (ΔE) is a very important parameter to determine the effect of the drying process of the product and was calculated with the help of the following equation;

$$\Delta E = \sqrt{(L_t - L_k)^2 + (a_t - a_k)^2 + (b_t - b_k)^2} \quad (5)$$

Where the values shown with the k index represent the related color parameters of the dried products, and the values shown with the t index represent the relevant color parameters of the fresh samples.

2.2.7. Specific Energy Consumption

In the present study, a digital watt-meter (Tt Technic PM-001, Turkey) was used to measure the total energy consumption (Ec) consumed by the dryer during operation (Taskin, 2020). The energy required to evaporate the unit mass of water in the product is the specific energy consumption (SEC) is calculated using the following equations (Eq.6). However, latent heat values of water and product were calculated using the following equation (Motevali et al., 2016).

$$SEC = \frac{E_c}{m_w} \quad (6)$$

Where, m_w is the amount of water removed from the product (kg).

3. RESULTS AND DISCUSSIONS

Initial and final moisture contents were determined as 9 and 0.1305 kg water kg drymatter^{-1}, respectively. Drying durations were determined as 50, 90, 100 and 120 minutes for purple dragon fruit and, 45, 85, 100 and 120 minutes for white dragon fruit. Drying time was 2.4 and 2.6 times shorter for purple and white dragon fruit compared to control conditions in the gum arabic pretreatment application. This has provided a significant advantage in terms of energy consumption. The shortest drying time after gum arabic pretreatment was measured in ultrasound pretreated samples. In addition, the highest energy consumption was obtained in the drying method without pretreatment. The statistical parameters (R^2, RMSE and χ^2) related to the experimental data and the estimation data obtained from 6 different thin layer drying equations were given in Table 1. It was found that the prediction model that gave the closest results to the experimental data was the Jena&Das model.

The time-dependent experimental moisture contents of white and purple dragon fruit dried by microwave drying at 300 W using different pretreatments and the estimated moisture contents calculated by the predictive model are presented in Figures 2 and 3. According to Figure 2, 66% of the moisture ratio of white dragon fruit in the first 20 minutes, followed by ultrasound pre-treatment, sucrose pre-treatment and non-pre-treatment drying method, respectively. It was determined that 35%, 17% and 10% moisture were removed from the product. Similarly, the moisture content of purple dragon fruit in the first 20 minutes of drying period for gum arabic, ultrasound, sucrose pre-treatment and non-pre-treatment drying methods, was determined as 60%, 31%, 20% and 13%, respectively (Figure 3). The slowest moisture release is in sucrose pre-treated products, which is associated with the reduction of water permeability by adding stickiness to the products with the effect of temperature (Yong et al., 2007). Bhagya Raj and Dash (2020) was found that 59% of the moisture was removed from the product in the first 20 minutes of drying the purple dragon fruit slices with microwave at 300 W without pretreatment. This result complies to present findings. Darvishi et al. (2016) determined that 65% of the moisture was removed from the product in the first 20 minutes of drying the kiwi slices with a 300 W microwave.

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Table 1. Statistical parameters regarding the modeling

Drying Cond.	Model	Logistic		Jena Das		Page		Midilli		Henderson and Pabis		Yağcıoğlu	
		Purple	White	Purple	White	Purple	White	Purple	White	Purple	White	Purple	White
Control	R^2	0,9898	0,9801	0,9959	0,9966	0,9924	0,9939	0,9964	0,9954	0,9082	0,8968	0,9849	0,969
	RMSE	0,0223	0,0348	0,0181	0,0165	0,0259	0,0231	0,0164	0,0196	0,0747	0,0875	0,0260	0,0407
	χ^2	6,14 10^{-4}	1,46 10^{-3}	3,81 10^{-4}	3,05 10^{-4}	7,43 10^{-4}	5,84 10^{-4}	3,33 10^{-4}	4,61 10^{-4}	6,16 10^{-4}	8,36 10^{-3}	7,87 10^{-4}	1,89 10^{-3}
Ultra sound	R^2	0,9941	0,9994	0,9975	0,9960	0,9962	0,9965	0,9930	0,9934	0,9638	0,9730	0,9892	0,9866
	RMSE	0,0237	0,0080	0,0156	0,0210	0,0196	0,0194	0,0235	0,0229	0,0525	0,0502	0,0313	0,0376
	χ^2	7,09 10^{-4}	8,14 10^{-5}	2,89 10^{-4}	5,30 10^{-}	4,29 10^{-4}	4,23 10^{-4}	6,60 10^{-4}	6,72 10^{-4}	3,08 10^{-3}	3,24 10^{-3}	1,16 10^{-3}	1,70 10^{-3}
Gum Arabic	R^2	0,9922	0,9983	0,9908	0,9941	0,9909	0,9921	0,9919	0,9909	0,9886	0,9558	0,9917	0,9975
	RMSE	0,0215	0,0103	0,0225	0,0136	0,0225	0,0180	0,0227	0,0227	0,0243	0,0444	0,0232	0,0133
	χ^2	5,84 10^{-4}	1,34 10^{-4}	6,03 10^{-4}	2,21 10^{-4}	5,65 10^{-4}	3,60 10^{-4}	6,55 10^{-4}	6,45 10^{-4}	6,59 10^{-4}	2,20 10^{-3}	6,37 10^{-4}	2,11 10^{-4}
Sucrose	R^2	0,9933	0,9848	0,9978	0,9966	0,9958	0,9887	0,9980	0,9954	0,9278	0,9197	0,9880	0,9805
	RMSE	0,0215	0,0302	0,0138	0,0180	0,0199	0,0332	0,0138	0,0209	0,0676	0,0707	0,0280	0,0315
	χ^2	5,80 10^{-4}	1,11 10^{-3}	2,24 10^{-4}	3,76 10^{-4}	4,38 10^{-4}	1,21 10^{-3}	2,38 10^{-4}	5,35 10^{-4}	5,08 10^{-3}	5,50 10^{-3}	9,21 10^{-4}	1,15 10^{-4}

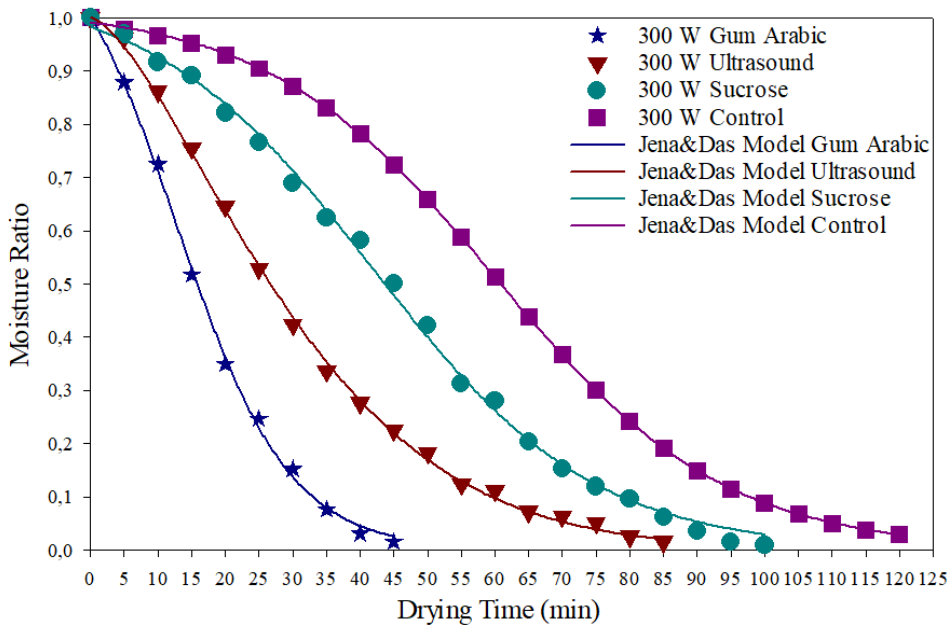

Figure 2. Time-dependent moisture ratio of white dragon fruit

Rehydration capacity is the ability to regain the moisture content of dried products when they are fresh, and it is an important parameter that determines the quality of the products. The increase in the rehydration capacity of dried products indicates that the quality of the product also increases (Tan et al., 2022). In this study, the highest rehydration capacity was measured in purple dragon fruit gum arabic pre-treated products, and this value was found to be 2.49 times higher than sucrose pre-treated drying. Likewise, the highest and lowest rehydration capacity in white dragon fruit, respectively; measured in gum arabic and sucrose pretreatment drying. It was determined that the re-absorption capacity of gum arabic pre-treated products was 1.49 times higher than the sucrose

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pre-treated dried samples. Nordin et al. (2014) reported that the highest rehydration capacity was obtained in microwave-vacuum combination when drying purple dragon fruit slices with microwave-vacuum, hot air and microwave-hot air methods.

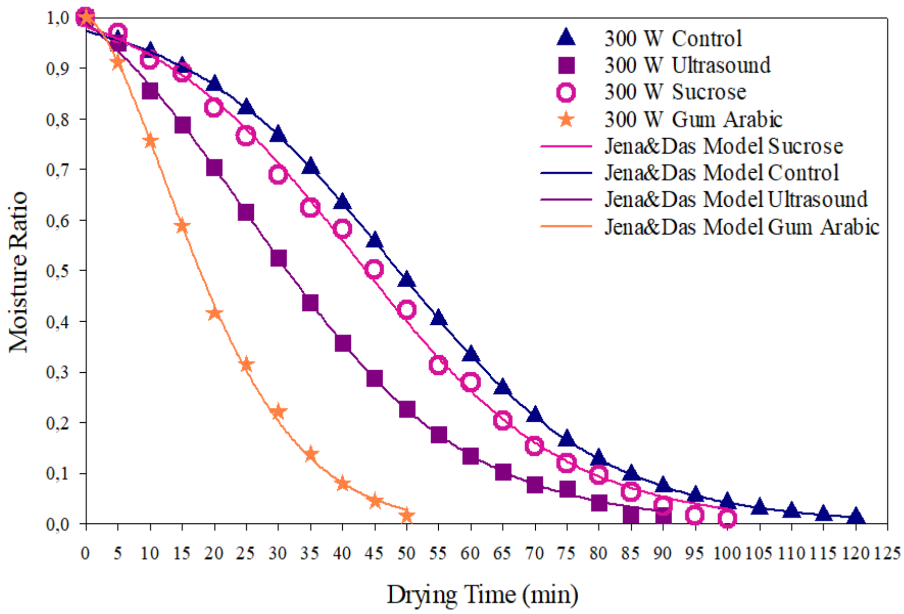

Figure 3. Time-dependent moisture ratio of purple dragon fruit

Table 2. Rehydration capacity of the dragon fruits

Pretreatments	Purple	White
Control	4,4	3,26
Gum Arabic	5,44	4,11
Sucrose	2,18	2,75
Ultrasound	4,41	3,2

In this study, color parameters of fresh and dried white and purple dried fruit were presented in Tables 3 and 4. The lowest value of the L*, which expresses the darkness and lightness of the color in relation to the brightness of the products for both dragon fruits, was measured in the dried products without pretreatment. It was found that the highest a* and b* values were obtained in control group. However, the chroma (C) value, which is an indicator of the light and pastel tone of the color, gave the values closest to the fresh product in gum arabic pre-treated products. Compared to the fresh product, it was determined that the total color change, which shows how much the product was affected by the drying process, was the most in the control group, and the least in the gum arabic pre-processed drying method. Haj Najafi et al. (2014) reported that when dragon fruit was dried at 35°C, the darkening of the color of the products increased with the increase of sucrose concentration. In the current study, the lowest L* color parameter was measured in the sucrose pre-treated dragon fruits. In a study conducted by Araújo et al., (2022), it was determined that ethanol pretreatment reduced the overall color change in convective drying of white and purple dragon fruit at 70°C.

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Table 3. Color parameters of fresh and dried white dragon fruit

Pretreatments	*L**	*a**	*b**	*C*	*ΔE*
Fresh	10.1±0.4	5.1±0.5	6.29±0.2	32.5±0.5	0.0±0.0
Control	0.76±1.0	1.68±1.4	1.68±1.4	4.41±1.7	28.45±1.5
Ultrasound	2.80±3.1	3.10±1.0	4.54±5.6	4.79±1.1	23.30±1.5
Sucrose	3.56±0.4	3.66±2.0	7.93±0.7	6.93±2.1	26.20±1.3
Gum Arabic	4.04±0.3	4.33±0.9	14.85±1.3	11.9±0.5	22.32±1.1

Table 4. Color parameters of fresh and dried purple dragon fruit

Pretreatments	*L**	*a**	*B**	*C*	*ΔE*
Fresh	11.62±0.4	30.61±0.3	-10.47±0.2	32.66±0.4	0.0±0.0
Control	2.78±0.3	13.63±1.2	1.99±1.4	1.78±1.3	26.56±1.5
Ultrasound	2.41±2.1	13.00±1.0	1.62±0.6	1.30±0.2	24.71±0.5
Sucrose	1.39±0.4	7.45±2.0	0.85±0.7	1.96±0.5	22.74±1.3
Gum Arabic	3.73±0.2	9.96±0.9	1.88±1.0	10.12±0.1	20.46±0.1

In this study, specific energy consumption results were given in Table 5. The greatest specific energy consumption was determined in the control group with the values of 27.17 and 26.95 kWh kg^{-1}, respectively. Additionally, the lowest specific energy consumption was obtained from Gum Arabic for white (11.78 kWh kg^{-1}) and purple (9.30 kWh kg^{-1}) dragon fruit.

Table 5. Specific energy consumption results

Pretreatments	Purple (kWh kg^{-1})	White (kWh kg^{-1})
Control	27.17	26.95
Gum Arabic	11.78	9.30
Sucrose	22.25	21.62
Ultrasound	18.88	18.94

4. CONCLUSIONS

In this study, the effect of different pretreatments on microwave drying of dragon fruit was determined. In the study, the shortest drying time for white and purple dragon fruit was measured in gum arabic pre-treated products. On the other hand, the longest drying time was obtained from the samples dried without pretreatment. The drying condition with the lowest and highest energy consumption in relation to the drying time, gum arabic has been a drying method with and without pre-treatment. In the drying process without pretreatment, darkening occurred in the products, and related to this, the drying condition with the lowest L value, which expresses the lightness and

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darkness of the color, was the control condition. The color values closest to the fresh product and the highest rehydration capacity were measured in gum arabic pre-treated products. As a result, the pre-treatment application of gum arabic has provided extremely important advantages in terms of drying performance, color and rehydration capacity of dragon fruit in microwave drying. Due to the benefits of gum arabic pre-treatment application, it is recommended that its use in drying works become widespread.

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