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Research Article

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Microwave-Assisted foam Mat Drying of Pumpkin Pulp and Development of a New Drying Model

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Abstract This study aims to investigate the effects of foam drying method on the moisture ratio, drying rate and color values of pumpkin puree at different microwave power densities and combinations of different power densities and fan assisted hot air. Foam stabilizer employed for the creation of foam was carboxymethyl cellulose, while soy protein served as the foaming agent. Pumpkin puree has a 100 (±0.03) g weight with an initial moisture level of 87.84% (w.b.) on wet basis were dried with microwave power and combination values of microwave power and FAHA until the moisture level was 14.47% (±0.005). Drying processes took 62, 24 and 13 minutes at varying microwave power densities. Fan assisted hot air trials lasted between 55 to 15 minutes. Using experimental data, a “new model” was developed to explain most trials, encompassing 12 thin layer drying models from prior research categorized as experimental, quasi-experimental, and theoretical. For comparison of model’s statistical parameters are considered such as R^2 , χ^2 and RMSE. The model with the smallest χ^2 and RMSE were chosen as the best model. Hence, the "new model" was identified as the equation that yielded the most accurate results aligning with the experimental data from the two different methods employed in the study. This determination excluded the microwave power densities of 1.8 Wg^{-1} and 5.4 Wg^{-1}. At power densities of 1.8 and 5.4 Wg^{-1}, the Jena-Das model equation was determined as the model equation giving optimum results. In addition, color and energy consumption values were obtained.

Keywords Cucurbitaceae, pulp, energy consumption, color, modelling

1. Introduction

Categorized under the Cucurbitaceae family, pumpkin is identified within the species of Cucurbita pepo, Cucurbita moschata, Cucurbita maxima, and Cucurbita mixta [27]. This family includes 118 genera and 825 species [11]. Pumpkin is grown in tropical and subtropical regions due to its high nutritional value, low polysaccharide content, and energy density [3].

Pumpkin is a versatile ingredient used in foods like cookies, soups and breads. In addition, cooking and pureeing processes also increase its potential. Additionally, its fibrous structure interacts well with water and glucose, making it valuable. It is used in bread, salads and cakes, and is also very popular in Türkiye [8]. Naturally dried pumpkin powder is used in baked goods, soups, and noodles, and it also naturally colors pasta. It increases the nutrition in bread and other foods due to its abundant carotene, vitamin, mineral and fiber content [22].

The availability of food varies between years and seasons. Therefore, it is important to have proper storage to meet the demand of consumers.

Drying, one of the preservation methods, can prevent microbial activity by reducing water content, limit reactions, and reduce weight, volume, transportation and storage costs [1]. This also inhibits microbial activity, limits reactions and reduces weight, volume and costs. On the other hand, advanced drying techniques such as foam drying allow high-quality products to be obtained at lower temperatures, preserving nutrients. At the same time, foam drying is attracting attention due to its advantages such as convenience, cost effectiveness and shorter processing time. Ensuring a consistent supply and meeting consumer demand necessitate proper storage due to the fluctuation in food availability throughout different seasons and years.

The process of transforming liquid or semi-liquid nutriment into a steady foam using agents, succeeded by drying with thin-layer, is a variable technique that facilitates rapid drying while minimizing nutritional loss, akin to the principles observed in spray or freeze drying [4]. Foam drying is cost-effective and yields powders that reconstitute well, conserving nutritional quality.

Foam mat drying has emerged as a successful technique for achieving high-quality production of fruit juice and pulp, owing to its simplicity, cost-effectiveness, and efficient water removal capabilities.

It's been applied successfully to alfonso mango , pineapple, sour cherry, banana, and papaya [20,12,4,24,13]. This method consistently preserves the sensory characteristics and nutritional value of fruit products.

This study aimed to transform pumpkin fruit into powder through the utilization of microwave and fan assisted drying with foam. Additionally, a novel mathematical model was devised to elucidate the drying process.

The experimental data underwent analysis employing 12 distinct thin layer drying equations alongside the newly developed model. Energy consumption was evaluated, and the color changes in dried products were compared with their fresh counterparts. The objective was to pinpoint the drying method that closely mimicked the fresh product concerning time, energy efficiency, and color alterations.

2. Materials and Methods

For this research, pumpkin fruits were procured from local bazaar. These fruits were preserved at +4°C up to analysis. Before conducting the analysis, the pumpkins underwent a process of washing, peeling, and slicing. Subsequently, they were boiled in hot water for approximately 15 minutes.

Following the boiling process, the pumpkin slices underwent further processing to form a uniform puree using a juicer (Mixer & Blender Set Beko BKK 2166 700 W). To facilitate the drying process and create a stable foam, a foaming agent comprising soy protein (SP) and a foam equalizer named carboxymethyl cellulose (CMC) were incorporated. Preliminary experiments were conducted, and a stable foam was achieved through a 3-minute whisking process.

Before the preparation, which was combined with an equal weight of foam consisting of 1% soy protein and 1% carboxymethyl cellulose based on the concentrations determined in the preliminary studies, the resulting mixture was thoroughly homogenized. Subsequently, the drying process was initiated by spreading the homogeneous mixture to a thickness of 1 cm, as illustrated in Fig. 1.

Figure. 1: Foamed pumpkin puree

The experiments were conducted employing a laboratory-scale fan-assisted microwave dryer, specifically utilizing the Arcelik MD 594 model from Turkey. The drying experiments involved two methods: microwave drying and fan-assisted microwave-hot air combination drying. Within the microwave drying method, three distinct microwave power levels (1.8, 3.6, and 5.4 Wg^{-1}) were applied. For the microwave-hot air combination method, various combinations of microwave power densities and temperatures were utilized, namely 1.8 , 3.6 , 5.4 Wg^{-1} at 100 and 150˚C.

During the drying process, approximately 100 g of pumpkin samples were periodically withdrawn at 1-minute intervals. These samples were then weighed using an analytical precision balance with an accuracy of 0.0001 g. The drying process continued until the samples reached a constant weight, indicating the completion of the drying process. The schematic representation of the pumpkin powder production through the foam is given in Fig. 2.

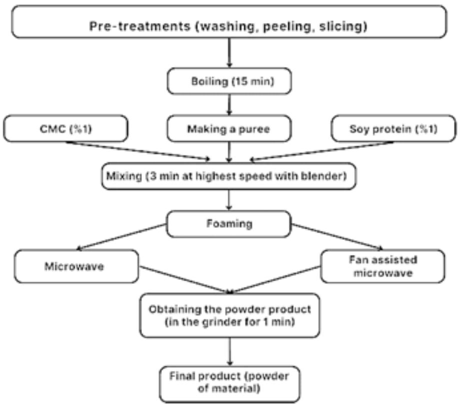

Figure. 2.:Pumpkin powder production flow chart

Determination of moisture content

Pumpkin pulp, weighing approximately 50 grams, was carefully placed into containers, and subsequently placed inside an oven set at 105°C. The samples were allowed to dry for a duration of 24 hours.

Moisture ratio

By changing of moisture presence as a function of time (M(t)), moisture ratio (MR) was assessed, the beginning moisture content of the samples (M0), and the equilibrium moisture content of the fruits (Me). It was ignored due to M_0 or M_t are higher than M_e [21].

$$MR = \frac{M(t)-M_e}{M_0-M_e} \qquad (1)$$

Drying rate

Drying rate was determined by calculating the changing of the moisture presence with drying duration curves using Eq. 2.

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

Where, DR represents evaporation from water from a gram dry matter per minute; Mt+dt: moisture presence at time t + dt (g water g dry matter^{-1}) ; M(t): moisture presence at moment t (kg water kg dry matter^{-1}); dt represents time (min) when the moisture content is calculated throughout the drying period.

Mathematical modeling

In the field of agricultural drying, various mathematical equations have been developed to describe and predict the drying characteristics of all kind of products. Table 1 offers an exhaustive compilation of thirteen empirical models frequently employed for simulating drying curves.

Table 1: Theoretical forms of mostly used and new model for drying

No	**Mathematical models**	
1	Newton	$MR=\exp(-kt)$
2	Page	$MR=\exp(-kt^n)$
3	Modified Page	$MR=a\exp[-(kt^n)]$
4	Logarithmic	$MR=a\exp(-kt)+c$
5	Two Term	$MR=a\exp(-k_1t)+b\exp(-k_2t)$
6	Verma et al.	$MR=a\exp(-kt)+(1-a)\exp(-gt)$
7	Midilli et al.	$MR=a\exp(-kt^n)+bt$
8	Henderson and Pabis	$MR=a\exp(-kt)$
9	Otsura et al.	$MR=1-\exp[-(kt^n)]$
10	Diffusion approximation	$MR=a\exp(-kt)+(1-a)\exp(-kbt)$
11	Jena&Das	$MR=a\exp(-kt+b\sqrt{t})+c$
12	Demir et al.	$MR=a\exp(-kt)^n+c$
13	(New Model)	$MR=\frac{a^b exp(-kt^n)}{c^t}+d$

The efficacy of these models was assessed through diverse statistical measures, encompassing the root mean square error (R_{MSE}), chi-squared (χ^2), and coefficient of determination (R^2). These statistical measures allow for the assessment of the accuracy and goodness-of-fit of the models. The calculations for RMSE, χ^2, and R^2 can be expressed as follows:

$$R^2 = 1 - \left[\frac{\sum_{i=1}^{N}(MR_{pre,i} - MR_{exp,i})^2}{\sum_{i=1}^{N}(MR_{pre,i} - MR_{pre,i})^2}\right] \qquad (3)$$

$$\chi^2 = \frac{\sum_{i=1}^{N}(MR_{exp,i} - MR_{pre,i})^2}{N - Z} \qquad (4)$$

$$RMSE = \left[\frac{1}{N}\sum_{i=1}^{N}(MR_{pre,i} - MR_{exp,i})^2\right]^{\frac{1}{2}} \qquad (5)$$

$$EF = \left[\frac{\sum_{i=1}^{N}(MR_{pre,i} - MR_{exp,average})^2 - (MR_{pre,i} - MR_{exp,i})^2}{\sum_{i=1}^{N}(MR_{pre,i} - MR_{pre,average})^2}\right] \qquad (6)$$

Where, $MR_{exp,i}$ and $MR_{pre,i}$ are experimental and predicted dimensionless MR values $MR_{exp,average}$ and $MR_{pre,average}$ are mean values of exp. and pre. MR values respectively; N is the number of experiments ; Z is number of constants of model. The most appropriate model equation for determining the drying characteristics of apple specimen is a model with the highest R^2 and the lowest χ^2 as well as RMSE values.

Color measurement

Color is a crucial factor that significantly impacts consumers' perception of product quality and taste. Individuals' perception of color is significantly influenced by the ambient light conditions. Commission Internationale de l'Eclairage (CIE) color space, the international color parameters widely accepted are L*, a*, and b*. L* signifies the luminosity or brightness of the color and spans from 0 (black) to 100 (white). The a* and b* components correspond to the green and blue axis for negative values, and the red and yellow axis for positive values.

Nevertheless, L*, a*, and b* values obtained obtained from product may not precisely mirror the color perception of consumers. Therefore, the α and C values were calculated from these parameters to better represent color perception.

The Hue angle is mathematically derived utilizing the a* and b* axes in the Lab* color space, chancing between 0° and 360°. It is linked to distinct color hues, such as red-violet at 0°, yellow at 90°, bluish-green at 180°, and blue at 270°. Research indicates the Hue angle value offers precise interpretation of the a* and b* values, encapsulating the hue value of these parameters [26].

The chroma (C) value, also known as color saturation or intensity, quantifies the vividness or strength of the color. The Hue angle amalgamates the redness and yellowness values, exhibiting higher values for vibrant colors and lower values for unvivid colors.

The equations used to calculate the C and α values are presented below [23]. In the literature, both the L*a *b* color space proposed by CIE and the Lab space suggested by Hunter Lab are commonly employed to represent the color of food products.

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

$$\alpha = tan^{-1}\left(\frac{b}{a}\right)$$

Developing a new model

In this study, in addition to the utilization of 12 existing thin layer drying models, a new model was developed specifically for pumpkin drying. Prior to its development, an extensive literature review was conducted, revealing that the proposed model has not been previously employed in any published sources. It is worth noting that for a newly developed model to gain acceptance and recognition in national and international publications, its application and validation in numerous studies are essential. Consequently, at present, the developed model is solely applicable for estimating the moisture content of pumpkin. Subsequent research focusing on different agricultural products will further validate the reliability and effectiveness of this developed model.

The equation of the developed model is as follows:

$$MR = \frac{a^b\, exp\,(-kt^n)}{c^t} + d$$

a: Coefficient (unitless), b : Coefficient (unitless), k: Kinetic constant (min^{-1}) , t : Drying time (min), n : Coefficient (unitless) , c: Coefficient (unitless), d: Coefficient (unitless)

Determining the energy consumptions

Electrical energy consumption of the microwave drying system was measured using a electricity meter (Tchibo, 267773), which was used to determine the energy consumption during the process. For comparing energy consumptions this parameter transformed to specific energy consumption (SEC). SEC was defined as an energy requirement for repel one gram of water from the samples during the drying process. It was quantified in terms of Wh g^{-1} (watt-hour per gram) and computed with the eq. 10. , as previously documented [5]:

$$E_s = \frac{E_c}{W_r}$$

Energy consumption of Watthour per gram water(Wh g^{-1} water), Specific energy consumption (Wh g^{-1} water) , Total used energy (Wh), total removed water (g)

Statistical Analysis

For statistical analyses Minitab package program was used. Mathematical models' nonlinear regression analyses were carried on in Minitab (version 19) to determine the parameters coefficients of the models. The outcomes of the nonlinear regression analyses for microwave drying of pumpkin samples from distinct microwave output powers included the coefficient of determination (R^2), chi-square value (χ^2), and root mean square error (RMSE). These statistical parameters were used to determine the appropriate of the models to the experimental data.

3. Results & Discussion

Determining of drying curves

Changes in the moisture presence of pumpkin samples, dried using two distinct methods that involve various microwave power densities and fan assisted microwave drying conditions over time, are depicted in Fig. 3 and Fig. 4.

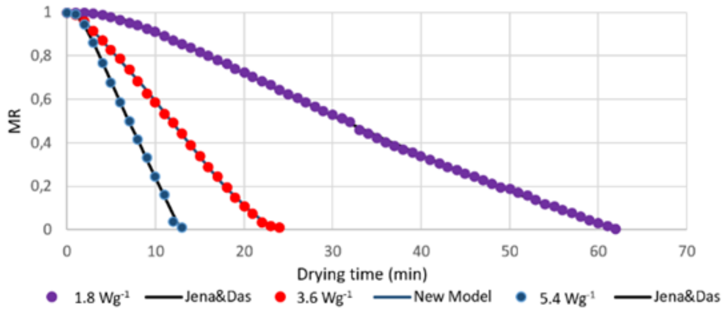

Figure 3: Changing of MR depending on drying time in microwave drying of pumpkin samples with different microwave power densities

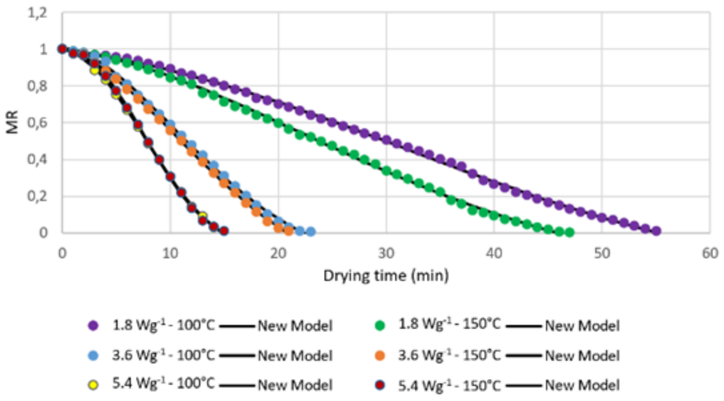

Figure 4: Changing of MR depending on drying time in combination drying of pumpkin samples with different microwave power densities and drying air temperatures.

The pumpkin foam underwent drying, reducing from the beginning moisture presence of 87.84% (w.b) to 14.47% (w.b) under all drying conditions. While the 1.8 Wg^{-1} microwave drying method was the longest drying method in the study with a drying time of 62 minutes, the drying trials were completed in 24 and 13 minutes depending on the drying power densities in the other two microwave drying methods (3.6 Wg^{-1} and 5.4 Wg^{-1}). Fan assisted microwave experiments proceeded between 15 and 55 minutes based on the temperature and power density. The shortest drying time occurs at 5.4 Wg^{-1}-100°C and 5.4 Wg^{-1}- 150°C, with a 13 min. drying duration were lasted in 4 times rapid than the slowest drying method.

Nevertheless, as the temperature increased in the combined drying method, needed time for drying was reduced to 8 min. Decrease in drying duration between the 100 and 150 °C at 3.6Wg^{-1} was 2 min. Notably, with the elevation of power in fan assisted method, a significant reduction in drying duration was observed. Nevertheless, there was no discernible difference in drying duration with the elevation in temperature in the 100 and 150 °C at 5.4W g^{-1}.

The study revealed that the parallel increase in temperature with rise in power levels in the combination method had no discernible impact on drying durations. Contrarily, in fan assisted method, the augmentation of power level, significantly reduced drying times, unlike the effect of temperature.

Franco et al. [7] found that the moisture content of foam-dried yacon water powders at three different temperatures (50ºC, 60ºC and 70ºC) decreased with increasing temperature. Likewise, Thuwapanichayanan et al. [25] found that the moisture value of foam-dried banana powders decreased as the temperature increased. Kılıç [14] dried the pumpkin with foam drying method at three different temperatures. It was observed that the moisture values of the pumpkin powders obtained at 50°C were higher than the moisture values of the powders at 60°C. In a study by Koç et al. [15], they carried out the microwave and hot air drying process of pumpkin using the foam drying method and examined the effect of drying parameters on drying kinetics. It has been determined that the microwave drying process was completed in a shorter time compared to hot air drying, due to the large evaporation area on the foam surface, as well as providing volumetric heating. In addition, while the increase in microwave and temperature power shortened the drying time, the drying times were prolonged with the increase of the foam thickness.

4. Drying rate

Drying rate curves, illustrating the drying duration dependency of microwave and fan assisted microwave methods, are presented in Fig. 5 and Fig. 6.

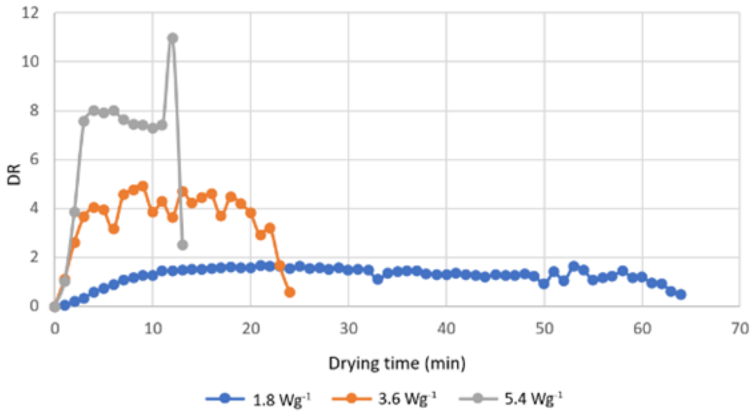

Figure 5: Changing of DR depending on drying time in microwave drying of pumpkin samples with different microwave power densities (1.8, 3.6 and 5.4 Wg^{-1})

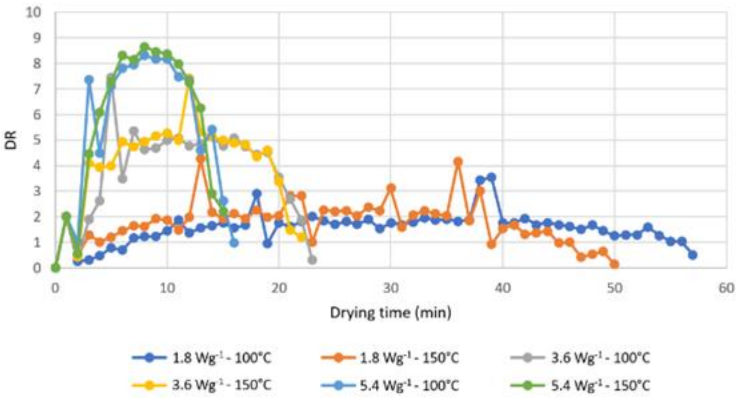

Figure 6: Changing of DR depending on drying time in combination drying of pumpkin samples with different microwave power densities and drying air temperatures.

Drying rate curves plays a crucial role in evaluate the efficiency of drying methods. Singularly microwave method showed that increasing in power parallelly increased drying rate. The lowest DR was obtained with 1.65 g_{water} / $g_{drymatter}$ at 1.8 W g^{-1} power density and highest DR with 10.95 g_{water} / $g_{drymatter}$ at 5.4 W g^{-1} power density.

Fan assisted microwave methods' DR values were recorded at 1.8 W g^{-1} with 100°C as the lowest DR with 3.55 g_{water} / $g_{drymatter.}$ Conversely, the highest drying rate was observed at 5.4 W g^{-1} with 150°C with 8.66 g_{water} / $g_{drymatter.}$ As evidenced by this, an increase in the DR of foam-dried pumpkins was observed with the simultaneous rise in power and fan assisted hot air's temperature.

Pumpkin drying using foam demonstrated a consistent decrease in drying rate over time across all power density temperatures. Additionally, instances of a constant rate drying phase were observed.

Throughout the drying of the pumpkins using foam, drying conducted at whole power levels and fan's temperatures primarily exhibited a diminishing rate in the drying duration. Between certain drying phases a constant drying rate was observed.

Maskan [17], conducted a study and bananas were dried by using three distinct methods; microwave, fan assisted microwave, and a mix of both. The outcomes of these methods were then compared. The results indicated that the DR escalated with an enhance in power density during microwave drying. Additionally, employing fan assisted after microwave drying led to an enhanced DR and a reduction in drying duration. Significantly, the results obtained from this integrated process showed no difference compared to other methods concerning color and re-watering capacity.

Close findings were reported of drying of various fruit pulps, such as mango , papaya , pumpkin , tomato and Cumbeba [19,13,5,23,6] foams. In these studies, it was observed that the drying rate is influenced by drying method, temperature, relative humidity and the thickness of the pumpkin layers.

Evaluation of mathematical modelling

The changes in moisture presence while the drying of foam-dried pumpkin puree using distinct drying methods were examined concerning drying duration. Total 13 drying models, along with a newly developed drying model, were employed to investigate this variation.

Mathematical models' statistical indicators such as R^2, χ^2, and R_{MSE} are presented in Table 2-4. Additionally, constants of models are detailed in Table 5.

Table 2: Comparing models of microwave method at various microwave power densities

Model	**1.8 Wg^{-1}**				**3.6 Wg^{-1}**				**5.4 Wg^{-1}**			
	RMSE	**χ^2**	**R^2**	**EF**	**RMSE**	**χ^2**	**R^2**	**EF**	**RMSE**	**χ^2**	**R^2**	**EF**
1	0.1070	0.0157	0.9467	0.8462	0.1099	0.0131	0.9608	0.8816	0.1264	0.0188	0.9588	0.8472
2	0.0207	0.0004	0.9958	0.9956	0.0299	0.0009	0.9919	0.9912	0.0330	0.0012	0.9899	0.9895
3	0.0198	0.0004	0.9961	0.9960	0.0254	0.0007	0.9940	0.9936	0.0319	0.0013	0.9906	0.9902
4	0.0161	0.0002	0.9973	0.9973	0.0169	0.0003	0.9971	0.9971	0.0155	0.0003	0.9976	0.9976

5	0.0350	0.0013	0.9887	0.9875	0.0442	0.0023	0.9829	0.9808	0.0486	0.0034	0.9792	0.9774
6	0.0373	0.0014	0.9870	0.9859	0.0272	0.0008	0.9944	0.9927	0.0323	0.0013	0.9926	0.9900
7	0.0054	3.18E-05	0.9997	0.9997	0.0092	0.0001	0.9991	0.9991	0.0124	0.0002	0.9984	0.9985
8	0.0779	0.0065	0.9432	0.9387	0.0822	0.0081	0.9392	0.9337	0.0872	0.0109	0.9319	0.9273
9	0.0613	0.0038	0.9660	0.9621	0.0745	0.0060	0.9522	0.9455	0.0726	0.0062	0.9534	0.9496
10	0.0373	0.0014	0.9870	0.9859	0.0479	0.0026	0.9795	0.9774	0.0531	0.0036	0.9750	0.9730
11	0.0047	2.39E-05	0.9997	0.9997	0.0112	0.0001	0.9987	0.9987	0.0119	0.0002	0.9986	0.9986
12	0.0161	0.0002	0.9973	0.9973	0.0169	0.0003	0.9971	0.9971	0.0156	0.0003	0.9976	0.9976
13	0.0054	3.26E-05	0.9997	0.9997	0.0067	6.09E-05	0.9995	0.9995	0.0122	0.0002	0.9985	0.9985

Table 3: Comparing models of fan assisted microwave method at 100°C

Fan assisted 100 °C												
Model	**1.8 Wg^{-1}**				**3.6 Wg^{-1}**				**5.4 Wg^{-1}**			
	RMSE	**χ^2**	**R^2**	**EF**	**RMSE**	**χ^2**	**R^2**	**EF**	**RMSE**	**χ^2**	**R^2**	**EF**
1	0.1160	0.0139	0.9407	0.8624	0.1302	0.0185	0.9562	0.8507	0.1377	0.0218	0.9510	0.8336
2	0.0304	0.0009	0.9915	0.9904	0.0251	0.0006	0.9948	0.9944	0.0221	0.0005	0.9961	0.9956
3	0.0243	0.0006	0.9941	0.9939	0.0240	0.0006	0.9952	0.9949	0.0188	0.0004	0.9971	0.9969
4	0.0238	0.0006	0.9941	0.9941	0.0267	0.0008	0.9936	0.9937	0.0293	0.0010	0.9923	0.9924
5	0.0474	0.0024	0.9791	0.9770	0.0457	0.0025	0.9838	0.9815	0.0473	0.0030	0.9828	0.9803
6	0.0523	0.0028	0.9740	0.9720	0.0439	0.0022	0.9872	0.9830	0.0456	0.0026	0.9856	0.9817
7	0.0093	9.42E-05	0.9991	0.9991	0.0119	0.0001	0.9987	0.9987	0.0074	7.57E-05	0.9995	0.9995
8	0.0920	0.0091	0.9188	0.9134	0.0936	0.0106	0.9293	0.9228	0.0987	0.0132	0.9210	0.9145
9	0.0725	0.0054	0.9533	0.9462	0.0695	0.0052	0.9618	0.9574	0.0688	0.0054	0.9645	0.9584
10	0.0523	0.0028	0.9740	0.9720	0.0509	0.0029	0.9796	0.9771	0.0566	0.0040	0.9749	0.9719
11	0.0108	0.0001	0.9987	0.9987	0.0131	0.0002	0.9984	0.9984	0.0126	0.0002	0.9985	0.9985
12	0.0238	0.0006	0.9941	0.9941	0.0267	0.0008	0.9936	0.9937	0.0293	0.0011	0.9923	0.9924
13	0.0095	0.0001	0.9990	0.9990	0.0117	0.0001	0.9987	0.9987	0.0070	8.3E-05	0.9995	0.9995

Table 4: Comparing models of fan assisted microwave method at 150°C

Fan assisted 150 °C												
Model	**1.8 Wg^{-1}**				**3.6 Wg^{-1}**				**5.4 Wg^{-1}**			
	RMSE	**χ^2**	**R^2**	**EF**	**RMSE**	**χ^2**	**R^2**	**EF**	**RMSE**	**χ^2**	**R^2**	**EF**

No.	1	2	3	4	5	6	7	8	9	10	11	12
1	0.1190	0.0148	0.9470	0.8652	0.1214	0.0162	0.9526	0.8580	0.1469	0.0249	0.9464	0.8188
2	0.0316	0.0010	0.9912	0.9904	0.0265	0.0007	0.9938	0.9931	0.0172	0.0003	0.9978	0.9975
3	0.0276	0.0008	0.9930	0.9927	0.0226	0.0005	0.9953	0.9950	0.0148	0.0002	0.9982	0.9981
4	0.0260	0.0007	0.9935	0.9935	0.0193	0.0004	0.9963	0.9963	0.0374	0.0017	0.9881	0.9882
5	0.0486	0.0025	0.9799	0.9775	0.0450	0.0025	0.9825	0.9804	0.0467	0.0029	0.9842	0.9816
6	0.0529	0.0030	0.9756	0.9733	0.0507	0.0030	0.9774	0.9751	0.0551	0.0038	0.9793	0.9744
7	0.0166	0.0003	0.9973	0.9973	0.0060	4.58E-05	0.9996	0.9996	0.0077	8.29E-05	0.9994	0.9994
8	0.0928	0.0094	0.9242	0.9180	0.0898	0.0099	0.9277	0.9221	0.1051	0.0150	0.9142	0.9072
9	0.0728	0.0055	0.9564	0.9495	0.0706	0.0055	0.9580	0.9518	0.0638	0.0047	0.9708	0.9657
10	0.0529	0.0030	0.9755	0.9733	0.0507	0.0030	0.9773	0.9751	0.0588	0.0043	0.9742	0.9709
11	0.0185	0.0003	0.9967	0.9967	0.0078	7.53E-05	0.9994	0.9994	0.0144	0.0002	0.9982	0.9982
12	0.0259	0.0007	0.9936	0.9936	0.0193	0.0004	0.9963	0.9963	0.0374	0.0019	0.9881	0.9882
13	0.0166	0.0003	0.9973	0.9973	0.0059	4.95E-05	0.9996	0.9996	0.0076	9.69E-05	0.9995	0.9995

Table 5: Model coefficients of chosen model

MODEL COEFFİCİENTS												
1.8 Wg^{-1} $^{\delta}$	a:	1.7791	k:	0.0190	b:	0.0589	c:	-0.8635				
3.6 Wg^{-1} $^{\beta}$	a:	23.5687	b:	0.0382	k:	7.08^{-05}	n:	3.1652	c:	1.0415	d:	-0.0860
5.4 Wg^{-1} $^{\delta}$	a:	2.7279	k:	0.0542	b:	0.0800	c:	-1.8065				
1.8 Wg^{-1}-100°C $^{\beta}$	a:	32.0747	b:	0.0425	k:	1.47^{-05}	n:	2.8626	c:	1.0112	d	-0.1441
3.6 Wg^{-1} -100°C $^{\beta}$	a:	2.0395	b:	0.2699	k:	0.0050	n:	1.8553	c:	1.0048	d:	-0.1987
5.4 Wg^{-1}-100°C $^{\beta}$	a:	16.6699	b:	0.0410	k:	0.0034	n:	2.3650	c:	1.0213	d:	-0.1099
1.8 Wg^{-1}-150°C $^{\beta}$	a:	1.1626	b:	1.7081	k:	0.00173	n:	1.7452	c:	1.0017	d:	-0.3024
3.6 Wg^{-1}-150°C $^{\beta}$	a:	2.8906	b:	0.2394	k:	0.00381	n:	1.9139	c:	1.0111	d:	-0.2836
5.4 Wg^{-1}-150°C $^{\beta}$	a:	449.7593	b:	0.0121	k:	0.00565	n:	2.2554	c:	1.0017	d:	-0.0838

The letter represents the best fits models for each experiment, δ: Jena&Das model , β: New model

In microwave drying, excluding 1.8Wg^{-1} and 5.4Wg^{-1} microwave power densities, the "New model" equation was selected as the most successful model with a coefficient of 0.999551 at 3.6Wg^{-1} microwave power density. For both drying at 1.8 Wg^{-1} and 5.4 Wg^{-1}, the "Jena-Das" model had the best estimation with the coefficients of determination 0.999775 and 0.998626.

However, under the conditions of microwave fan assisted combination drying method (1.8 W g^{-1}-100°C, 1.8 W g^{-1}-150°C, 3.6 W g^{-1}-100°C, 3.6 W g^{-1}-150°C, 5.4 W g^{-1}-100°C, 5.4 W g^{-1}-150°C), the best prediction model was determined as the “New Model” equation , where the coefficients of determination were 0.999067, 0.997358, 0.998784, 0.999658, 0.99956 and 0.999508, respectively.

Similar to numerous studies involving various agricultural products, drying was conducted in this study using both microwave and convective methods with comparable microwave power densities and temperatures. The data obtained during an experiment were subsequently turned into prediction data using the thin-layer drying equations utilized.

Color

L*, a*, b*, C*, Hue angle and ΔE values of raw and dried pumpkin are provided in the Table 6. Variance analysis results revealed microwave power density and temperatures has a noteworthy effect on all color parameters.

Table 6: Comparison of color parameters of fresh and microwave dried material

Drying method	L*	a*	b*	C*	Hue	ΔE
Fresh fruit	**52.37^{d} (±1.46)**	**8.99^{ab} (±0.71)**	**42.4^{ab} (±1.63)**	**43.34^{ab} (±1.72)**	**78.03^{e} (±0.56)**	**-**
1.8 Wg^{-1}	69.91^{ab} (±2.4)	7.74^{de} (±0.49)	42.22^{ab} (±0.4)	42.92^{ab} (±0.33)	79.6^{bc} (±0.72)	17.59^{ab} (±2.43)
3.6 Wg^{-1}	70.43^{ab} (±1.05)	7.94^{cde} (±0.38)	44.34^{a} (±0.31)	45.04^{a} (±0.37)	79.84^{b} (±0.4)	18.20^{ab} (±1.05)
5.4 Wg^{-1}	62.9^{c} (±1.06)	9.63^{a} (±0.32)	38.58^{c} (±0.36)	39.76^{c} (±0.33)	75.98^{f} (±0.49)	11.23^{c} (±0.99)
1.8 Wg^{-1}-100˚C	72.68^{ab} (±2.66)	6.96^{e} (±0.29)	43.86^{a} (±0.72)	44.41^{ab} (±0.7)	80.98^{a} (±0.45)	20.47^{ab} (±2.69)
1.8 Wg^{-1}-150˚C	74.52^{a} (±1.06)	7.03^{e} (±0.34)	44.83^{a} (±1.08)	45.38^{a} (±1.08)	81.08^{a} (±0.44)	22.39^{a} (±1.12)
3.6 Wg^{-1} -100˚C	69.6^{b} (±0.81)	8.81^{abc} (±0.1)	44.1^{a} (±1.01)	44.97^{a} (±0.99)	78.69^{de} (±0.27)	17.33^{b} (±0.90)
3.6 Wg^{-1}-150˚C	62.27^{c} (±5.94)	8.53^{bcd} (±1.22)	43.7^{a} (±4.41)	44.52^{a} (±4.55)	78.98^{cd} (±0.61)	10.47^{c} (±6.44)
5.4 Wg^{-1}-100˚C	61.54^{c} (±3.28)	9.4^{ab} (±0.4)	37.89^{c} (±1.43)	39.03^{c} (±1.49)	76.06^{f} (±0.12)	10.50^{c} (±2.10)
5.4 Wg^{-1}-150˚C	62.07^{c} (±1.13)	9.59^{a} (±0.13)	40.15^{bc} (±0.71)	41.27^{bc} (±0.68)	76.56^{f} (±0.36)	10.01^{c} (±0.94)

In the determination of the color parameters, the effect of foam drying was ignored because the same type of foaming agent and stabilizer was used in the mashed pumpkin samples. Microwave power densities and temperatures were taken into account in the study. The L*, a*, and b* values of fresh pumpkin were determined as 52.37, 8.99, and 42.4, respectively.

The L*, a*, b*, C*, Hue and ΔE values of dried pumpkin was obtained in distinct methods shown a variety of 61.54-74.52, 6.96-9.63, 37.89-44.83, 39.03-45.38, 75.98-81.08, 10.01-22.39, and 85.64-93.89, respectively.

In the literature, it has been observed that the C. maxima type pumpkin has different values for its color. Perez and Schmalko [18] stated that the L*, a* and b* values of fresh pumpkin belonging to the C. maxima species were 52.77, 8.33 and 32.84, respectively. Images of pumpkin purees that are fresh and dried with distinct drying methods are shown in the Fig. 1 and Fig. 7.

Figure.7: Pumpkin powders obtained from different microwave power densities and drying air temperatures.

Accordingly, the brightness (L*) value closest to the fresh product in the microwave drying method was measured in the samples dried with 5.4 Wg^{-1}. In the combination method made with microwave and fan assisted hot air, the closest brightness (L*) value to the fresh product was observed in the samples dried at 5.4Wg^{-1}-100°C. It was determined that all drying methods had a statistically significant effect on gloss at 95% significance level. When investigating the effect of microwave power density on the L* value in the microwave drying method, an increase in the L* value was observed with the increment of power density. The highest L* value was found in the samples dried at a power density of 3.6Wg^{-1}.

During the experimentation of fan assisted method, the samples dried at 1.8Wg^{-1}-100°C and 1.8Wg^{-1}-150°C exhibited the highest L* values. However, an inverse relationship was observed between L* values and microwave power density in this combination method.

When analyzing the impact of microwave power density on the a* redness value in the microwave drying method, the redness value closest to that of the fresh product was observed at 5.4 Wg^{-1}, while the furthest redness value occurred at 1.8 Wg^{-1}. In the combination drying method, the closest a* value to the fresh product is observed at 5.4 Wg^{-1}-100°C, the farthest a* value occurred at 1.8 Wg^{-1}-100°C. It was observed that the darkening of the samples increased with the increase in the redness (a*) value. This evaluation suggests that darkening was observed in the pumpkin samples as a consequence of the experiments conducted using the combination drying method of 5.4 Wg^{-1}-100°C and 5.4 Wg^{-1}-150°C. It was observed that all drying methods had a significant effect on the redness (a*) value at the $P<0,05$.

When the b* (yellowness) values were examined, the b* (yellowness) values closest to the fresh product were obtained as a result of the experiments with 1.8 Wg^{-1} in the samples dried by microwave drying method. When the yellowness (b*) values were examined in the combination study, as a result of the experiments with 1.8 Wg^{-1} and 3.6 Wg^{-1} microwave power densities, values almost close to each other were obtained and it was determined that the values increased compared to the fresh ones. The values farthest from freshness were obtained in combination studies performed with 5.4 Wg^{-1}. As a result, the yellowness (b*) values increased with the enhance of microwave power, and it was assumed that high power density had a negative effect on yellowness (b*).

Chroma and hue angle values of the samples prepared by drying with foam were also calculated. Chroma indicates the intensity and clarity of color. Hue angle, which is a quality related to hue, is also an important color parameter. As a result of the experiments made with the microwave drying method, the Chroma values closest to the fresh product were obtained with 1.8 Wg^{-1}. In the drying method with microwave power density and fan assisted hot air, it was observed that the Chroma value closest to the fresh values was obtained at 1.8 Wg^{-1}-100°C. In terms of chroma values, the highest values were obtained in 1.8 Wg^{-1} and 3.6 Wg^{-1} combination studies, while the lowest values were obtained at 5.4 Wg^{-1}. In addition, it was observed that microwave and combination drying methods had a significant effect on chroma at the 95% significance level.

Chroma and hue angle values of the samples prepared by drying with foam were also calculated. Chroma indicates the intensity and clarity of color. Hue angle, which is a quality related to hue, is also an important color parameter. As a result of the experiments made with the microwave drying method, the Chroma values closest to the fresh product were obtained with 1.8 Wg^{-1}. In the drying method with microwave power density and fan assisted hot air, it was observed that the Chroma value closest to the fresh values was obtained at 1.8 Wg^{-1}-100°C. In terms of chroma values, the highest values were obtained in 1.8 Wg^{-1} and 3.6 Wg^{-1} combination studies, while the lowest values were obtained at 5.4 Wg^{-1}. In addition, it was observed that microwave and combination drying methods had a significant effect on chroma at the 95% significance level.

Chroma which indicates saturation has been analyzed and gac fruit's saturation value enhanced with the elevation of temperature in the foam drying process. Notably, the powder material dried at a higher temperature exhibited the higher saturation value [2].

Hue angle results demonstrated the highest color angle value was obtained with 3.6 Wg^{-1} in the microwave drying method, while the lowest value was measured with 5.4 Wg^{-1}. In the combination trials, the highest color angle values were obtained with 1.8 Wg^{-1}-150°C, and the lowest color angle values were measured at 5.4 Wg^{-1}-100°C. In terms of ΔE values, it was noted that the overall color change decreased with the rise in microwave power level in microwave drying method. Additionally, in the combination method, a notable decrease in ΔE values was observed with the concurrent application of higher microwave power levels and temperatures. Indistinguishable findings have been reported in drying studies conducted by other researchers [9,16].

Specific energy consumption

The specific energy consumption values of pumpkin samples dried using various microwave power levels and fan's air temperatures are illustrated in Fig 8.

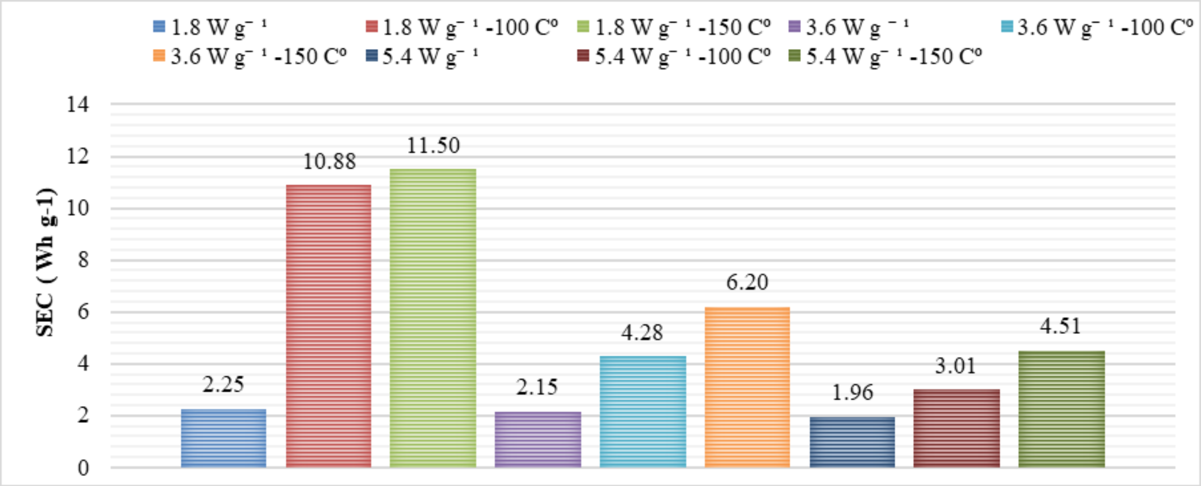

Figure 8: Specific energy consumptions of different microwave power densities and drying air temperatures.

As a result of drying the pumpkin samples with microwave power densities of 1.8, 3.6, 5.4 Wg^{-1}, the specific energy consumption values were determined as 2.27, 1.95, and 1.94 Whg^{-1} water, respectively. On the other hand, combination of microwave power density and fan assisted microwave at 1.8 Wg^{-1}-100˚C, 1.8 Wg^{-1}-150˚C, 3.6 Wg^{-1}-100˚C, 3.6 Wg^{-1}-150˚C, 5.4 Wg^{-1}-100˚C and 5.4 Wg^{-1}-150˚C, the specific energy consumption values of the pumpkin samples were calculated as 10.6, 10.41, 3.91, 5.14, 2.8, 4.5, respectively. Based on the obtained results, it was established that the specific energy consumption decreased by escalation of microwave power densities. Conversely, in the combination drying method, it was observed with the increasing of temperature of fan assisted method energy consumptions has increased. The drying times of the samples had a considerable impact on energy consumption.

By decreasing the drying duration, energy requirement will decrease. Raghavan et al. [19] dried cranberry fruit at power densities of 0.75 Wg^{-1}, 1.0 Wg^{-1} and 1.25 Wg^{-1} and reported that the drying time was shortened with the increase of microwave power density, and accordingly, the total amount of energy consumed decreased. Horuz et al. [10] convection drying at 50°C and 70°C, microwave drying at 120-180 W and combinations of these methods were performed with sour cherry fruit. They reported that the method with the highest total energy consumption and specific energy consumption was convective drying at 50°C, associated with the longest drying time.

Conclusion

The pumpkin puree underwent drying through a microwave and fan assisted microwave drying method, while the study also examined potential variances between the two drying methods. As a result, discrepancies were noted concerning drying time, the formation of powder and the color of the final product. Even the microwave and combination method provide an advantage on higher levels considering drying duration and energy efficiency it caused to darkening.

The main purpose of microwave and combination method is to enhance drying effectiveness by incorporating multiple drying methods into a singular procedure. The study considers it advantageous to strive for improved product quality through such combination drying experiments.

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