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Original article

Microwave Drying of Persimmon Puree Using Foam Mat Technique

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Abstract

In this study, it was aimed to determine the possibilities of drying persimmon with a microwave-assisted fan and foam mat method is the best for drying time, color and energy consumption. Persimmon puree, initially containing 82.90 % moisture content, was dried using a foam drying method augmented with microwave and fan combinations until the moisture content decreased to an average of 1.9 % ± 1.13. Soy protein (1%) and maltodextrin (1%) were employed as foaming agents in the foam drying process. Microwave drying trials conducted at 1.8 Wg-1, 3.6 Wg^{-1}, and 5.4 Wg^{-1} lasted 62, 22, and 14 minutes, respectively. Combination trials at 1.8 Wg^{-1}, 3.6 Wg^{-1}, and 5.4 Wg^{-1} at 100 °C lasted 57, 23, and 13 minutes, respectively, and at 150 °C for 47, 21, and 14 minutes, respectively. Twelve thin-layer drying equations were applied to determine the drying models. Each trial's drying rate, color parameters, and energy consumption were analyzed. The lowest color change observed at highest power density and temperature (5.4 Wg-1 & 150 °C). Külcü, Alibaş , Jena-Das and Midilli models emerged as the most suitable empirical equations, evidenced by the lowest root mean square error values. Statistical analyses categorized color parameters and energy consumption. The optimal energy efficiency was achieved with the 5.4 Wg^{-1} microwave drying method, yielding an energy consumption value of 2.12 Whg^{-1}.

Keywords: Microwave drying, Foam mat, color, Specific energy consumption.

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INTRODUCTION

The persimmon (*Diospyros kaki* Thunb.) is originated in China and in can cultivate in Mediterranean region of Türkiye and called as "Trabzon persimmon" (Tülek ve Demiray, 2014). It is important to dry and preserve the persimmon fruit due to its perishability, also drying allows to more useability on different ways. Persimmon is known as it strengthens the immune system and helps with cancer prevention (Bölek ve Obuz, 2014). This persimmon is rich in bioactive compounds like ascorbic acid, carotenoids, and condensed tannins (Gu et al., 2008), which are known for their numerous benefits to health such as antioxidant, anti-carcinogenic, anti-inflammatory, cardioprotective, and anti-hypercholesterolemic effects (Ge et al., 2017; Mamet et al., 2017).

Food products exhibit variability in availability due to seasonal, periodic, and annual fluctuations, necessitating effective storage solutions to ensure the accessibility and meet demands of consumers. Drying fruits is widely adopted and accepted as a safe method for preserve products. The primary purpose of drying is to inhibit the growth of microorganisms and biochemical reactions that may occur in the product by eliminating free water. This process prolongs the shelf life of the product by reducing the microbial population to levels at which reproduction is no longer possible. Compared to dried products, powder product needs way lower storage space which offers efficient method. Recent advancements in drying technology have introduced innovative methods, such as foam drying, which enables the production of high-quality products at lower temperatures, thereby preserving the nutritional content of the produce. The appeal of foam drying lies in its ease of application, cost-effectiveness, and faster processing times.

One of these drying methods, microwave drying (*MD*) offers faster drying time and advantageous of energy consumption comparing to convective drying processes. Addition of microwave drying to connective drying resulteded in %70 energy saving in garlic cloves (Sharma and Prasad, 2006). Because of low drying time, uniform heat dissipation, final product quality, and low energy consumption increases microwave drying's popularity (Bettega el al., 2014; Yan et al., 2010). Higher microwave power caused to retention of soluble sugar, soluble and insoluble tannin vitamin C, total phenol, and antioxidant activity but reduced to soluble protein and vitamin E (Wei et al., 2022; Qin et al., 2022).

In literature most of dryings made by persimmon slices but no study founded about combination permission puree and foam mat drying combination on hot air assisted of microwave drying (*HAAMD*). The objective of this study was to determine the drying kinetics of foam mat persimmon puree with *MD* and *HAAMD* also investigate of color change and energy consumption.

MATERIAL and METHOD

Material

Persimmon samples were sourced from local markets. Prior to the experiments, the persimmons were washed, sliced, and using a juicer made puree (Beko BKK 2166 700 W). Foam stability was achieved by adding 1% soy protein and 1% maltodextrin as foaming agents. To create the foam, the puree and foaming agents were whisked together for 3 minutes. The resulting puree was then spread onto plates with a thickness of 1 cm. Microwave dryer was used to conduct the trials. The study tested three main power levels (1.8 Wg^{-1}, 3.6 Wg^{-1}, 5.4 Wg^{-1}) and the combine with fan-assisted temperatures of 150 and 100 °C.

Drying equipment and drying method

Persimmon samples, each 100 g of weight were put in the drying oven at 105 °C for 24 h to determine the moisture content. Moisture analysis, which is essential for assessing the drying characteristics, was subsequently performed.

A drying trial was carried out at three main power densities at 540, 360, and 180W. Additional hot air assist was applied to these power densities with 100 °C and 150 °C. The persimmon puree dried as 100 g in all trials for this reason power densities converted to specific power densities as 5.4, 3.6 and 1.8 Wg^{-1} for better understanding, and comparability with other studies. Every minute material weighed until reaching constant weight during drying to calculate drying rates (*DR*). Drying rate indicates the effectiveness of drying and shows the variation of weight change during drying period (Maskan, 2000). Moisture ratio (*MR*) was calculated for each trial to calculate empirical models' parameters. Eq 1. Was used to calculate *MR* values.

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

M_t: is the moisture content dry basis at any time t; M_0: the initial moisture content; M_e: the equilibrium moisture content.

Empirical drying models were used in permission drying were tabulated (Table 1). To compare the models' performance criteria statistical parameters were used.

Table 1. Empirical drying models used for drying

No	Mathematical models		References
1	Newton	MR= exp(-kt)	Ayensu (1997)
2	Page	MR= exp(-kt^n)	Agrawal and singh (1997)
3	Modified Page	MR= a exp[-(kt^n)]	White et al. (1981)
4	Logarithmic	MR= a exp(-kt)+c	Yıldız et al. (2001)
5	Two Term	MR= a exp(-k$_1$t)+b exp(-k$_2$t)	Sharaf-Elden et al. (1980)
6	Verma et al.	MR= a exp(-kt)+(1-a)exp(-gt)	Verma et al. (1985)
7	Midilli et al.	MR= a exp(-kt^n)+bt	Sacilik and Elicin (2006)
8	Henderson and Pabis	MR= a exp(-kt)	Akpınar et al. (2006)
9	Diffusion approximation	MR= a exp(-kt)+(1-a) exp(-kbt)	Toğrul and Pehlivan (2003)
10	Jena & Das	MR=a exp(-kt+b√t)+c	Jena and Das (2007)
11	Alibaş	MR = aexp((-k.tn)+(bt))+g	Alibas (2012)
12	Külcü et al.	$\mathrm{MR} = \frac{a^b \exp(-kt^n)}{c^t} + d$	Külcü et al. (2024)

Energy consumptions during drying were measured by digital electricity meter. Energy requirements for drying converted to specific energy consumption (*SEC*) similar to power densities. *SEC* defines energy requirement to evaporate one gram water from sample using by eq 2.

$$E_S = \frac{E_c}{W_r} \quad (2)$$

Where, E_S: *SEC* (Whg^{-1}); E_C: Consumed energy for drying (Wh); W_r: Water mass removed (g).

Color parameters

Drying causes a change in color and this change makes an impact on consumers' decision. Main color parameters are L*, a*, and b*. L* indicates the brightness of color and stands between 0 (black) and 100 (white), a* and b* indicates green/red at negative values and blue/yellow at positive values (Fig 1).

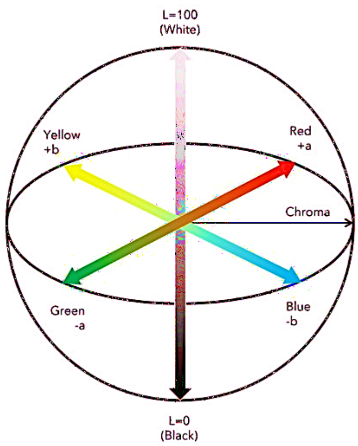

Fig. 1. Graphical description of CIELAB (L*a*b*) Scale

Generally, color perception doesn't directly affect by L*, a*, and b* so, hue angle (α) and chroma (C) values calculated for better description. Hue angle is a combination of a*, and b* values and access to color ranging 0° to 360°. It gives specific tint such as red violet (0°), yellow (90°), bluish green (180°), and blue (270°). Chroma (C) indicates color's vividness, and this parameter also affects perceptions of consumers.

$$C=\sqrt{(a^2+b^2)} \quad (3)$$

In order to determine overall color change in dried and fresh fruit total color change (ΔE) was calculated by Eq 4.

$$\Delta E=\sqrt{(L_0-L)^2+(a_0-a)^2+(b_0-b)^2} \quad (4)$$

Where, L_0= Luminosity of fresh material; a_0= redness/greenness of fresh material; b_0= yellowness/blueness of fresh material; L= Luminosity of dried material; a= redness/greenness of dried material; b=yellowness/blueness of dried material.

Data analysis

Following trials non-linear regression analysis was performed using MATLAB for estimating model parameters and model criteria such as R^2, χ^2, and RMSE were evaluated. Statistical analyses were conducted using SPSS. Duncan multiple comparison test was selected for compare parameters at $p<0.05$ level.

RESULTS and DISCUSSION

Moisture ratio

İnitial moisture content of persimmon determined as 82.9% and after oven drying persimmon weight of 100 g dropped to 16.9 g which determined as constant weight. Persimmon samples are dried using three main power density and combination with two different temperatures. Persimmon's beginning moisture content was 82.9 % reduced to average of 1.9 % after different drying applications. At lowest power density (1.8 Wg^{-1}) additional temperature made two different effects, even though temperature of 100 °C caused to extend the drying time, other hand 150 °C shortened drying time. At different power densities almost no effect was observed in terms of drying time, so additional hot air application is considered as insignificant especially combined with foam mat method. Trials varied between 13 and 63 minutes (Fig 2). The longest drying observed at 1.8 Wg^{-1} & 100 °C compared this time to 1.8 Wg^{-1} density it is considering that hot air at low temperature (100 °C) may cause to keep the moisture. Additional hot air applications made a significant effect between two different temperature levels. However, this difference gap gets closer with increasing power density. Each increasement of 1.8 Wg^{-1} caused to reduce drying time 36 min and 8 min. Dried product's weight exceeds 100 grams, it is believed that the additional fan-supported drying effect may change. In addition, the thickness of dried material also an important factor.

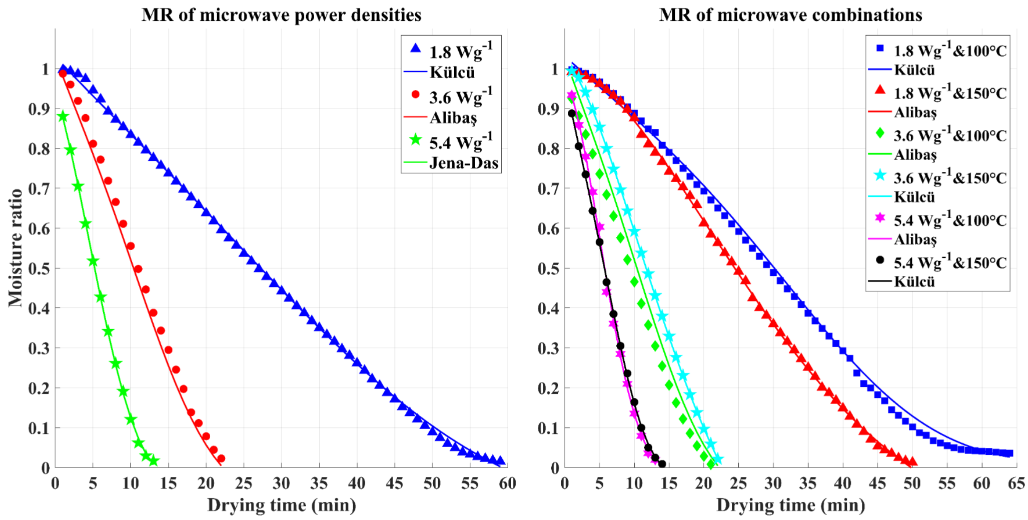

Fig. 2. Moisture ratio change during *MD* and *HAAMD*

Drying rate

Robustness and effectiveness of drying can illustrated by drying rate curves. These curves reflect a drying rate change overtime (Fig 3). Most of the time the drying rate increases in a few minutes due to material's inner temperature increases as well and reaches the highest point, then reduction in drying rate is observed as a reason of moisture content decreases. Non-homogeneous experimental conditions and products can lead to variations in the drying rate (Çelen, 2019). Due to this reason drying a puree form of material gains more homogeneous drying. Drying of persimmon with 200, 300, 400 and 500W power density resulted 115,105, 90 and 66 minutes respectively for 1:5 pulse ratio cycle (Borah et al., 2023). Although two times of power increase drying of persimmon slices as 280 and 560W resulted the drying time was between 54 and 24 min, respectively which resulted more than 2 times reduction in drying time shows that power has great impact on drying time (QIN et al., 2022). The highest drying rate obtained at 5.4 Wg^{-1} and temperatures over 9 g/min at. Difference in microwave drying has shown a significant change between power levels and the drying rate affected by drying time. Additional hot air application shows identical results at same power density. Average drying rates were 1.47, 3.77 and 6.15 for 1.8, 3.6 and 5.4 Wg^{-1} power densities and temperatures respectively. There was a bigger impact of hot air on lower power densities.

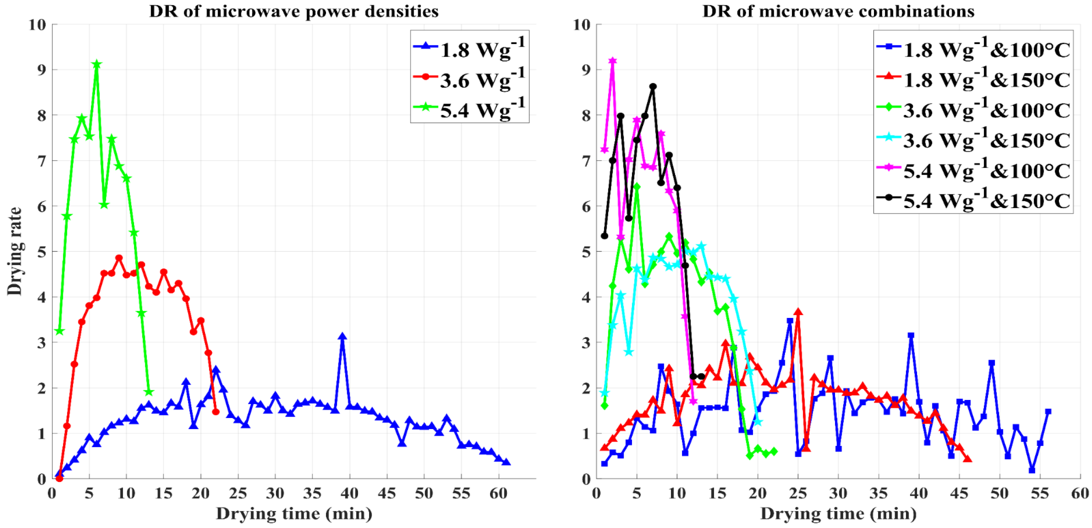

Fig. 3. Drying rate change during *MD* and *HAAMD*

Mathematical modelling

Drying describes by mathematical models. Mathematical models are empiric models that estimates drying curves by considering statistical parameters such as R^2, χ^2 and RMSE and compared these parameters to select best model (Table 2-4). Considering statistical parameters, Külcü, Alibaş Jena & Das and Midilli models showed the best fits. Best model's model constants are represented in Table 5.

Table 2. Comparison of models of *MD*

Model	1.8 Wg^{-1}			3.6 Wg^{-1}			5.4 Wg^{-1}		
	RMSE	χ^2	R^2	RMSE	χ^2	R^2	RMSE	χ^2	R^2
1	0.0924	0.0088	0.9697	0.1065	0.0124	0.9657	0.0752	0.0066	0.9748
2	0.0288	0.0008	0.9919	0.0223	0.0005	0.9953	0.0318	0.0012	0.9893
3	0.0261	0.0007	0.9933	0.0193	0.0004	0.9963	0.0157	0.0003	0.9972
4	0.0120	0.0001	0.9985	0.0162	0.0003	0.9972	0.0175	0.0004	0.9962
5	0.0701	0.0052	0.9537	0.0365	0.0016	0.9877	0.0284	0.0011	0.9915
6	0.0398	0.0016	0.9850	0.0292	0.0009	0.9936	0.0179	0.0004	0.9962
7	0.0183	0.0003	0.9965	0.0059	4.28^{E-05}	0.9996	0.0079	9.02^{E-05}	0.9992
8	0.0701	0.0052	0.9537	0.0763	0.0071	0.9452	0.0601	0.0052	0.9612
9	0.0397	0.0016	0.9849	0.0402	0.0018	0.9849	0.0376	0.0018	0.9845
10	0.0093	9.44^{E-05}	0.9990	0.0078	7.6^{E-05}	0.9993	0.0053	4.17^{E-05}	0.9996
11	0.0091	9.05^{E-05}	0.9991	0.0051	3.4^{E-05}	0.9997	0.2495	3.47^{E-05}	0.9997
12	0.0066	4.97^{E-05}	0.9995	0.0052	3.85^{E-05}	0.9997	0.0096	$3.98E^{E-05}$	0.9997

Table 3. Comparison of models of *HAAMD* (100ºC)

100 °C									
Model	**1.8 Wg^{-1}**			**3.6 Wg^{-1}**			**5.4 Wg^{-1}**		
	RMSE	χ^2	R^2	RMSE	χ^2	R^2	RMSE	χ^2	R^2
1	0.1107	0.0126	0.9628	0.1143	0.0143	0.9641	0.1009	0.0120	0.9721
2	0.0211	0.0004	0.9961	0.0227	0.0005	0.9954	0.0228	0.0006	0.9953
3	0.0186	0.0003	0.9968	0.0207	0.0004	0.9961	0.0149	0.0002	0.9977
4	0.0324	0.0011	0.9903	0.0196	0.0004	0.9963	0.0288	0.0010	0.9914
5	0.0385	0.0015	0.9879	0.0391	0.0018	0.9869	0.0297	0.0012	0.9920
6	0.0415	0.0018	0.9858	0.0348	0.0013	0.9916	0.0390	0.0019	0.9858
7	0.0150	0.0002	0.9979	0.0070	5.9^{E-05}	0.9995	0.0126	0.0002	0.9983
8	0.0826	0.0072	0.9429	0.0816	0.0080	0.9415	0.0716	0.0074	0.9525
9	0.0415	0.0018	0.9857	0.0431	0.0021	0.9839	0.0393	0.0020	0.9857
10	0.0213	0.0004	0.9958	0.0087	9.3^{E-05}	0.9992	0.0155	0.0003	0.9975
11	0.2959	0.0949	0.2220	0.0063	5.1^{E-05}	0.9996	0.0125	0.0002	0.9983
12	0.0151	0.0002	0.9988	0.0067	6.1^{E-05}	0.9995	0.0125	0.0002	0.9983

Table 4. Comparison of models of *HAAMD* (150ºC)

150 °C									
Model	**1.8 Wg^{-1}**			**3.6 Wg^{-1}**			**5.4 Wg^{-1}**		
	RMSE	χ^2	R^2	RMSE	χ^2	R^2	RMSE	χ^2	R^2
1	0.1158	0.0139	0.9586	0.1132	0.0141	0.9612	0.0796	0.0074	0.9711
2	0.0195	0.0003	0.9967	0.0219	0.0005	0.9953	0.0340	0.0013	0.9883
3	0.0177	0.0003	0.997	0.0204	0.0004	0.9959	0.0165	0.0003	0.9970
4	0.0242	0.0006	0.9944	0.0141	0.0002	0.9979	0.0196	0.0004	0.9954
5	0.0379	0.0015	0.9881	0.0382	0.0017	0.9864	0.0312	0.0013	0.9902
6	0.0418	0.0018	0.9852	0.0418	0.0020	0.9835	0.0201	0.0005	0.9954
7	0.0067	4.99^{E-05}	0.9995	0.0028	9.84^{E-06}	0.9999	0.0084	9.89^{E-05}	0.9991
8	0.0857	0.0079	0.9366	0.0801	0.0078	0.9390	0.0647	0.0058	0.9565
9	0.0418	0.0018	0.9852	0.0418	0.0020	0.9835	0.0410	0.0021	0.9822
10	0.0098	0.0001	0.9990	0.0029	1.09^{E-05}	0.9999	0.0113	0.0001	0.9984
11	0.0066	4.85^{E-05}	0.9995	0.0060	4.79^{E-05}	0.9996	0.0052	4.25^{E-05}	0.9996
12	0.0066	5.01^{E-05}	0.9995	0.0028	1.08^{E-05}	0.9999	0.0052	4.78^{E-05}	0.9996

Table 5. Best models' model parameters

MODEL COEFFİCİENTS												
1.8 Wg^{-1K}	**a:**	1.01865	**b:**	5.90150	**k:**	1.21^{E-06}	**n:**	3.44746	**c:**	1.02113	**d:**	-0.06866
3.6 Wg^{-1A}	**a:**	-0.34021	**k:**	0.00177	**g:**	2.04224	**b:**	0.10713	**c:**	1.37427		
5.4 Wg$^{-1\ J}$	**a:**	-0.01279	**k:**	0.28598	**b:**	2.22859	**c:**	0.96616				
1.8 Wg^{-1} -100°C^{M}	**a:**	0.98725	**k:**	0.00123	**n:**	1.85100	**b:**	-0.0010				
3.6 Wg^{-1} -100°C^{A}	**a:**	-0.35605	**k:**	0.00086	**g:**	2.20971	**b:**	0.09773	**c:**	1.39779		
5.4 Wg^{-1} -100°C^{A}	**a:**	1.00838	**k:**	0.01338	**g:**	2.05100	**b:**	-0.02539	**c:**	-0.03994		
1.8 Wg^{-1} -150°C^{A}	**a:**	1.19704	**k:**	0.00375	**g:**	1.60285	**b:**	0.00396	**c:**	-0.2030		
3.6 Wg^{-1} -150°C^{K}	**a:**	7.05330	**b:**	0.17399	**k:**	0.00693	**n:**	1.64165	**c:**	1.00572	**d:**	-0.38742
5.4 Wg^{-1} -150°C^{K}	**a:**	1.18342	**b:**	-0.00727	**k:**	0.00075	**n:**	3.03101	**c:**	1.08972	**d:**	-0.02775

Upper case represents best fits; A= Alibaş ; K= Külcü et. al. ; J= Jena & Das ; M= Midilli

Color

Color parameters of fresh and dried persimmon fruit are given in Table 6. Fresh fruit's L*, a*, and b* values were determined as 23.49, 4.06, 8.92 respectively, after different drying power densities and temperatures L*, a*, b*, and C* values of persimmon obtained as in the ranges of L= 27.21-44.53, a= 5.31-16.49, b= 17.83-28.37, and c= 18.6- 32.22 respectively. Highest color difference obtained at 5.4 Wg^{-1}&100 °C by considering overall color change (*ΔE*). The highest L value obtained in 1.8 Wg^{-1} method.

Overall color chance defined by Zachary Schuessler (Anonymous, 2024a) delineates the standard perception ranges as follows: 1.0: Imperceptible to the human eye; 1-2: Detectable upon close inspection; 2-10: Noticeable at a glance; 11-49: Colors exhibit greater similarity than dissimilarity; 100: Colors are precisely opposite. Upon evaluating all applications, it is evident that the Delta E value reaches a threshold where colors exhibit greater similarity than dissimilarity color differences are immediately discernible except 5.4 Wg^{-1}& 150 ˚C takes place as Noticeable at a glance. Color luminosity tend to reduce with reducing humidity (Vilhena et. al., 2020). Fresh samples have the lowest L value, which shows that these samples have the darkest appearance. However, in general studies, it is observed that the color darkens after drying (Varol et al., 2024; Dadalı et al., 2007). The reason for the increase in brightness may be due to the decrease in the c parameter as well as the color not being distributed homogeneously. It can also be understood that the dried products are more homogeneous, and their standard deviations are low. Considering total color changes (ΔE), it is seen that the closest color value to the fresh product is the 5.4 Wg^{-1}& 150 ˚C. Additional hot air may cause this reason considering previous studies. Some studies in contrast reported that drying on higher hot air temperatures resulted to higher L values (Erdem et al, 2018; Pilli et al., 2008). Drying in only power densities resulted in lower browning index value comparing to additional hot air. Browning index is an unwanted case due to shows material as burnt. Drying only power densities is more desired among hot air dryings.

Table 6. Change of color parameters after dryings

	Method	L*	a*	b*	C*	Hue	ΔE	BI
Microwave	Fresh	23.49^{e} (±3.32)	4.06^{e} (±0.52)	8.92^{e} (±2.56)	9.81^{e} (±2.55)	64.93^{bc} (±3.45)	-	62.10^{d} (±24.94)
	1.8 Wg^{-1}	42.63^{a} (±1.49)	16.49^{a} (±0.39)	25.43^{b} (±0.50)	30.3^{a} (±0.52)	57.03^{fg} (±0.69)	28.16^{ab} (±1.39)	94.23^{c} (±3.79)
	3.6 Wg^{-1}	36.06^{c} (±1.64)	13.23^{c} (±0.67)	19.24^{d} (±0.54)	23.35^{c} (±0.7)	55.48^{g} (±1.23)	18.71^{c} (±0.97)	142.52^{a} (±15.65)
	5.4 Wg^{-1}	41.48^{ab} (±1.02)	15.27^{ab} (±0.83)	28.37^{a} (±0.53)	32.22^{a} (±0.86)	61.71^{cde} (±0.86)	28.77^{a} (±1.30)	132.89^{ab} (±1.25)
100 °C	1.8 Wg^{-1}	38.4^{bc} (±3.15)	14.21^{bc} (±2.21)	27.61^{a} (±1.05)	31.10^{a} (±1.07)	62.8^{cd} (±4.06)	26.12^{b} (±1.98)	114.51^{abc} (±2.74)
	3.6 Wg^{-1}	36.69^{c} (±0.74)	10.07^{d} (±0.22)	23.25^{c} (±0.11)	25.34^{b} (±0.17)	66.58^{b} (±0.4)	20.39^{c} (±0.43)	114.67^{abc} (±3.84)
	5.4 Wg^{-1}	43.11^{a} (±0.23)	13.29^{c} (±0.21)	28.08^{a} (±0.30)	31.07^{a} (±0.35)	64.67^{bc} (±0.16)	28.93^{a} (±0.41)	140.82^{ab} (±2.18)
150 °C	1.8 Wg^{-1}	41.48^{ab} (±1.02)	15.27^{ab} (±0.83)	28.37^{a} (±0.53)	32.22^{a} (±0.86)	61.71^{cde} (±0.86)	28.77^{a} (±1.30)	100.62^{c} (±7.63)
	3.6 Wg^{-1}	38.38^{bc} (±0.62)	15.25^{ab} (±0.35)	27.18^{a} (±0.39)	31.17^{a} (±0.51)	60.71^{de} (±0.24)	26.08^{b} (±0.72)	121.01^{abc} (±1.01)
	5.4 Wg^{-1}	27.21^{d} (±0.27)	5.31^{e} (±0.06)	17.83^{d} (±0.32)	18.6^{d} (±0.33)	73.41^{a} (±0.11)	9.73^{d} (±0.39)	113.58^{bc} (±2.10)

Energy consumption

Energy consumption was measured across all power densities and fan-assisted combinations for each trial. In the context of general manufacturing, energy is a critical factor for profitability and sustainability. The microwave method offers rapid drying compared to the traditional sun-drying method, making it a strategic choice. To provide a clear measure of efficiency, energy consumption was converted into specific energy consumption, which indicates the energy required to remove water per gram. The results showed that energy consumption values ranged from 2.06 to 13.69 Whg^{-1} (Fig. 4), with the lowest values achieved using the microwave drying method. However, the use of additional fan assistance significantly increased energy consumption. Higher microwave power densities resulted in lower overall energy consumption due to reduced drying times. Conversely, increasing the hot air temperature led to higher specific energy consumption, except at a power level of 1.8 Wg^{-1}. The most influential factor affecting energy consumption was drying time. Although there was considerable variation at lower power levels, this variation diminished as power levels increased. The optimal energy efficiency was observed at 5.4 Wg^{-1}, with a specific energy consumption of 2.06 Whg^{-1}. Specific energy consumptions of persimmon, kumquat and pumpkin fruits were minimum at 460W, 5.4 Wg^{-1} and 5.4 Wg^{-1} respectively (Çelen, 2019; Varol et al., 2024; Külcü et al.,2024). Addition of 40W microwave power density to 70 °C hot air temperature and 1ms^{-1} air velocity resulted 70% energy saving compared to without microwave (Sharma and Prasad, 2006). Pre-treated persimmons were first exposed to hot air and then dried using microwave energy at various power densities (6.8, 10.7, 22, 30.8, and 40 W/g). The optimal power density, considering factors such as drying time, rehydration ability, color assessment, and textural properties, was found to be 10.7 Wg^{-1} (Jia et al., 2019).

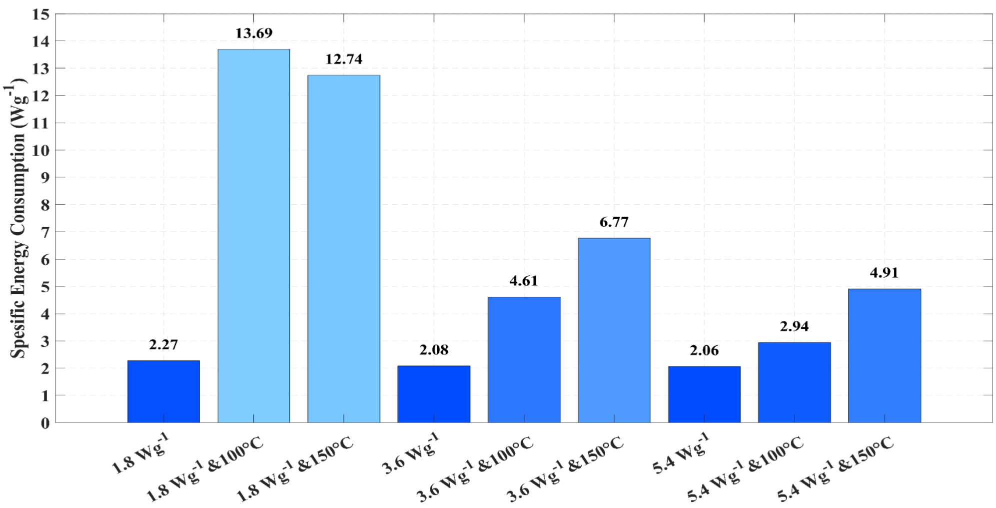

Fig. 4. Energy consumptions at different microwave power and temperature levels

These findings underscore the importance of selecting appropriate drying methods and power settings to minimize energy consumption and enhance efficiency in manufacturing processes. By carefully balancing power density and drying time, significant energy savings can be achieved, contributing to more sustainable and cost-effective production.

Conclusions

The persimmon puree underwent drying through a microwave and fan-assisted microwave drying method. Even though the microwave and combination methods provide faster drying, considering energy efficiency, the additional hot-assist causes an enormous increase in energy consumption. While this difference in energy consumption was greater at low power levels, it decreased as the power density increased. Increasing power density caused the product to darken. The lowest total color change occurred at 5.4 Wg^{-1}& 150 °C , with the closest trial to this value being 5.4 Wg^{-1}. Most of the trials provided the best fits with the Külcü and Alibaş models. Drying should be done using only microwave power densities, and considering energy efficiency and color change, a power density of 5.4 Wg^{-1} is recommended.

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