Microwave-Assisted Foam Mat Drying of Kumquat Puree and Investigation of Some Parameters

Hürkan Tayfun Varol[1]*, *Sevil* Karaaslan[1], *Recep* Külcü[1], and *Damla Su* Sivri[1]

[1]Isparta University of Applied Sciences, Faculty of Agriculture, Department of Agricultural Machinery and Technologies Engineering, Isparta, Turkiye

Abstract. Kumquat puree, with the initial moisture content of 81.02 ± 0.8 (w.b) on wet basis, were dried using two different methods, microwave, and fan assisted hot air microwave (FAHA) until moisture content of kumquat was reduced to average of 25.02 ± 1.35 w.b. Microwave trials at 1.8 , 3.6, and 5.4 Wg^{-1} lasted for 51, 19 and 12 min, respectively. FAHA trials at 1.8 , 3.6, and 5.4 Wg^{-1} at 100 ˚C and 1.8 , 3.6, and 5.4 Wg^{-1} at 150 ˚C lasted for 46, 38, 18, 15, 12 and 11 minutes, respectively. For foam drying, Soy protein (1%) and Maltodextrin (1%) were used as foaming agent, and carboxymethyl cellulose (1%) was used as foam stabilizer. After the drying trials, dried kumquat was powdered. The scope of this study, a comparison of measurements of moisture with that of the predicted results was made, obtained from 13 thin layer drying models. Further, drying rate, color parameter and energy consumptions were compared for each trial. For all microwave and FAHA trials, Kulcu et. al. (Unpublished) model was the most appropriate models depending on lowest chi-square value and root mean square error values. Color and specific energy consumptions (SEC) were categorized by using (SPSS) and chosen the best efficiency condition for drying as considering SEC. The most suitable drying process according to SEC was obtained at 5.4 Wg^{-1} microwave drying method with value of 1.94 Whg^{-1}.

---

* Corresponding author: hurkanvarol@isparta.edu.tr

1. Introduction

Kumquat (*Fortunella margarita* L.)) belongs to the Rutaceae family, such as mandarin, orange, lemon and has an edible skin. It is the best known of the genus Fortunella which is closely related to citrus [1]. It is named kumquat in various countries and called “gold orange” in China [2]. This variety of kumquat has an oblong shape and bright orange color. Citrus fruits are rich in vitamin, kumquat is also nutrient-rich fruit contains phytochemicals such as vitamin C, carotenoids, flavonoids and essential oils.

Kumquat can be consumed fresh as well as processed and used as additives in fruit juice, jam, and carbonated drinks. Also, as in this study, it can be powdered and can stored for many long times. Leaves and kumquat itself are using as a traditional medicine in China owing to vital elements and playing an important role in health in a dietary, treatment of diabetes [3]. İt can also be use include candying, liqueur, marmalade, jam, jelly and sauce [2].

Food products vary in availability by season, period, and year, requiring proper storage for consistent accessibility and meeting consumer demand. Drying is a popular and safe method for preserving fruits. Powdered products require less storage space than dried ones, making it a more efficient option for kumquats. It's also advantageous for transportation.

Drying tech advances include new methods like foam drying, which produces top-notch items at lower temps, keeping produce nutrients intact. Foam drying's appeal stems from easy use, cost-efficiency, and quicker processing.

Foam drying converts foods into stable foam with agents, followed by thin-layer drying. It's versatile, reduces drying time, and maintains nutrition [4]. This method competes with spray and freeze drying, costs less, and yields powders with great reconstitution properties, preserving nutritional value.

Foam mat drying has proven to be a successful method for producing high-quality juice and/or pulp of various fruits, thanks to its simplicity, cost-effectiveness, and efficient water removal capabilities.

Studies have demonstrated its successful application in the production of fruit products such as sour cherry, banana, alfonso mango, carrot and papaya [4-8]. This method offers a reliable and efficient means of producing high-quality fruit-based products while preserving their sensory attributes and nutritional value.

The aim of this study was to investigate the drying of kumquat fruit using foam drying, microwave and combined microwave-fan assisted drying methods to obtain kumquat powder. The experimental data obtained from the drying process was analyzed using 13 different thin layer drying equations and the best model was selected. The specific energy consumption during the drying process was also determined, and a comparison was made between the color changes in the dried products and the fresh product. Furthermore, the study aimed to identify the drying method that yielded results closest to the fresh product based on drying time, energy consumption, and color parameters.

2. Material and Method

2.1 Material

In this study, kumquat samples were purchased from local markets in Isparta province. The samples were stored in a refrigerator at a temperature of +4°C until they were ready for trails. Prior to trials, the kumquats were washed and sliced. Then the kumquats were processed into a homogeneous puree using a juicer. To create a stable foam for the drying process, as a foaming agent soy protein (1%) and maltodextrin (%1) and a foam stabilizer called carboxymethyl cellulose (CMC) (1%) were used. Initial tests created stable foam via 3-min whisking with a Beko BKK 2166 700 W Mixer & Blender Set.

After preparation kumquat puree, it was mixed with foam (1% soy protein, 1% maltodextrin, 1% carboxymethyl cellulose) based on preliminary study findings. The blend was well mixed, and then dried by spreading it 1 cm thick.

Foam drying trials were conducted using a fan assisted microwave dryer (Arcelik MD 594). Three main power densities 1.8, 3.6, and 5.4 Wg^{-1} and combination these with temperature of 100 and 150 ˚C were the tested. The kumquat samples were weighed every minute during drying by using a precise balance (0.0001 g accuracy). Drying continued until constant weight was reached, signaling process completion.

2.2 Determination of moisture content

Around 50 g of puree was put in containers and placed in a 105°C oven for 24 hours. Moisture analysis, vital for understanding drying, followed AOAC [9] method, calculated using Equation 1, with three replicates for accuracy.

$$\%moisture = \frac{M_1 - M_2}{m} * 100 \quad (1)$$

in this equation;
$M_{1;}$ Wet sample + container weight brought to constant weight (g)
M_2; Dried sample weight + container weight brought to constant weight (g)
m; Sample weight received (g)

2.3 Moisture ratio

The moisture ratio (MR) was found based on the moisture content as a function of time (t) (M(t)), the initial moisture content of the samples (M_0), and the equilibrium moisture content of the samples (M_e). It was neglected because M_e is much lower than M_0 or M_t [10].

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

2.4 Drying rate

The drying rate (DR) was found by taking the derivatives of the moisture content versus drying time curves with Equation 3 below.

$$DR = \frac{M_{t+dt} - M_t}{d_t} \tag{3}$$

where: DR, drying rate (g water g dry matter^{-1}min^{-1}); M t dt: Moisture content at time t+dt, (g water g dry matter^{-1}); Nt is the moisture content at time t (kg water kg dry matter^{-1}) and dt is the time (min) when the moisture content is calculated during the drying period [11].

2.5 Mathematical modeling

In agricultural drying, numerous mathematical models describe product drying. Table 1 lists 13 empirical models for simulating drying curves. One of model is unpublished Kulcu at al. model. Their performance assessed using statistical metrics like root mean square error (R_{MSE}), chi-squared (χ^2), coefficient of determination (R^2) and model efficiency (EF) [12], indicating model fit and accuracy. Calculations for χ^2 and R_{MSE} are as follows:

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

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

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

where $MR_{exp,i}$ and $MR_{pre,i}$ are experimental and predicted dimensionless MR values $MR_{exp,average}$ and $MR_{pre,average}$ are average values of experimental and predicted MR values respectively; N is the number of trials; and Z is the number of model constants. The most acceptable model for defining the drying properties of apple samples is a model with the highest R^2 and the lowest χ^2 as well as RMSE values [13].

Table 1. Commonly used models 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$_1$t)+b exp(-k$_2$t)
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√t)+c
12	Demir et al.	MR=a exp(-kt)^n+c
13	Kulcu et al.	$\mathrm{MR} = \frac{\mathrm{a^b exp(-kt^n)}}{\mathrm{c^t}} + \mathrm{d}$

2.6 Color measurement

Color profoundly affects how consumers perceive product quality and taste [14]. Perception depends on ambient light. In the CIE (Commission Internationale de l'Eclairage) color space, L*, a*, and b* are key international color parameters. L* indicates luminosity (0-black, 100-white). a* and b* relate to green/blue and red/yellow axes respectively, with negative and positive values.

Measured L*, a*, and b* values don't directly reflect color perception of consumers. To address this, Hue angle (α) and chroma (C) are computed from these values. Hue angle derives mathematically from a* and b* in Lab* color space, ranging 0° to 360°. It aligns with specific hues like red-violet (0°), yellow (90°), bluish-green (180°), and blue (270°). Studies have shown that the Hue value provides a more accurate interpretation of the a* and b* values, as it represents the angle value of these parameters [15].

Chroma (C), or color intensity, gauges color vividness. It considers redness and yellowness, higher for vibrant and lower for dull colors. Equations for C and α values are shown below [16]. Both CIE's Lab* and Hunter Lab's Lab color spaces are commonly used in the literature to depict food product color.

$$C = \sqrt{(a^2 + b^2)} \tag{7}$$

$$\alpha = tan^{-1}\left(\frac{b}{a}\right) \tag{8}$$

For assessing the overall color difference between dried and fresh fruit, the total color change (ΔE) was calculated by Equation 9 [17];

$$\Delta E = \sqrt{(L_0 - L)^2 + (a_0 - a)^2 + (b_0 - b)^2} \tag{9}$$

2.7 Determining energy consumption

Electrical energy consumption was measured by using a digital electricity meter (Tchibo, 267773). Specific energy consumption, the energy needed to remove one unit of water per gram, was defined in watt-hour per gram (Wh g^{-1}) using the following equation, as previously reported by Unadi et al. [18] and Varith et al. [19]:

$$E_s = \frac{E_c}{W_r} \tag{10}$$

E_s :Specific energy consumption (Wh g^{-1} water)
E_c: Amount of consumed electrical energy (Wh)
W_r :Mass of water removed from the sample (g)

2.8 Statistical Analysis

Statistical analyses were performed using Minitab and SPSS. Non-linear regression analysis was conducted in Minitab to estimate the parameters of the equations. The results of the regression analysis at different microwave output powers included the R^2, χ^2, and R_{MSE}. These statistical parameters were used to evaluate the goodness-of-fit of the models to the experimental data.

3. Results and Discussion

3.1 Determination of drying curves

The variation of moisture content of kumquat samples dried with 2 different drying methods including different microwave power densities and hot air conditions over time is presented in Fig. 1 and Fig. 2. Kumquat foam was dried from the initial moisture content of 81.02% (w.b) present to average 25.02 % (w.b) at all drying conditions. The longest drying time obtained at 1.8 Wg^{-1} power density, trails took at other power densities 19 and 12 minutes respectively (3.6 Wg^{-1} and 5.4 Wg^{-1}).

Microwave hot air combination drying trials lasted between 46 and 11 minutes depending on the applied microwave power density and temperature. In addition, the shortest drying methods, 5.4 Wg^{-1}- 150°C, recorded with a 11-minute drying time in the study, were completed in almost 4 times shorter than the longest drying method (1.8 Wg^{-1} microwave drying).

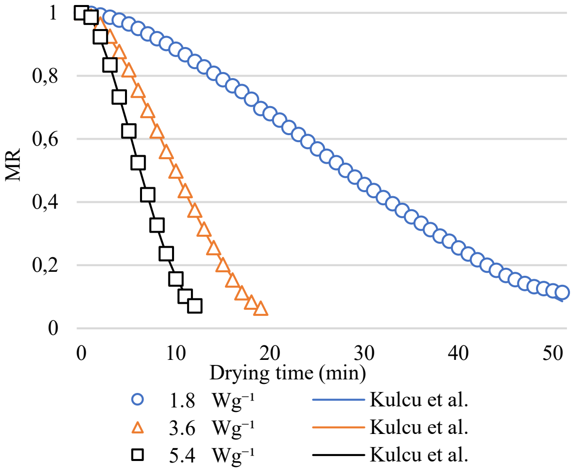

Fig. 1. Changing of MR with different microwave power densities

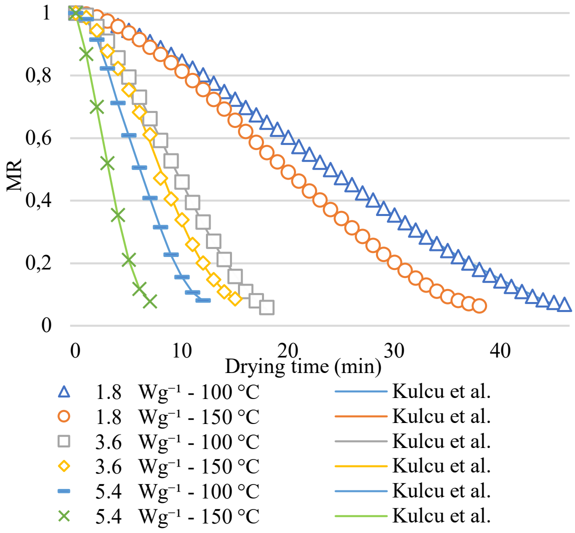

Fig. 2. Changing of MR with different microwave power densities and drying air temperatures

However, with the increase in temperature in the combined drying method (1.8Wg^{-1}-100°C; 1.8 Wg^{-1}-150°C) the drying times were shortened by 7 minutes. The reduction in drying times between 3.6W-100°C and 3.6W-150°C methods is 3 minutes. With the increase of microwave power density in the combination method, a significant decrease in drying times occurred. However, almost no (1 min) change was observed in the drying times with the increase in temperature in the 5.4Wg^{-1}-100°C and 5.4Wg^{-1}-150°C combination methods.

In the study, it was observed that the temperature increased in parallel with the increase in microwave power density in the combination method did not have any effect on the drying times. However, in the combination study, the increase in microwave power densities, in contrast to the temperature, significantly shortened the drying times.

3.2 Drying rate

The drying rate curves depending on the drying time of microwave and FAHA combination drying methods are given in Fig. 3 and Fig. 4. These curves are important for comparing the effectiveness of drying methods and determining which method provides faster drying rates. In the microwave drying method, the increase in the microwave power density applied to the samples caused the drying rate of the samples to increase. The drying rate was determined as the highest value with 8.25 g water/g dry matter.min at 5.4Wg^{-1} power density in the trials made with this method.

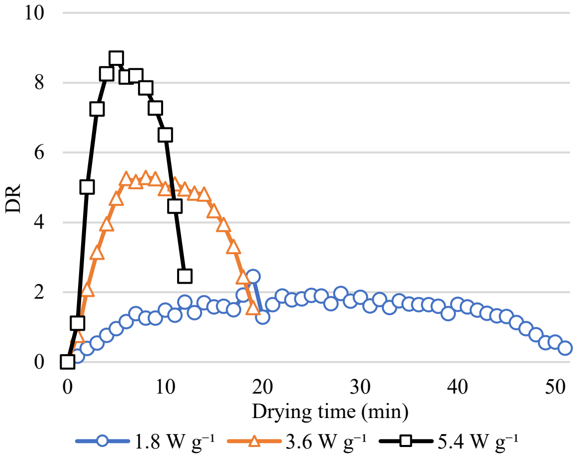

Fig. 3. Changing of DR with different microwave power densities

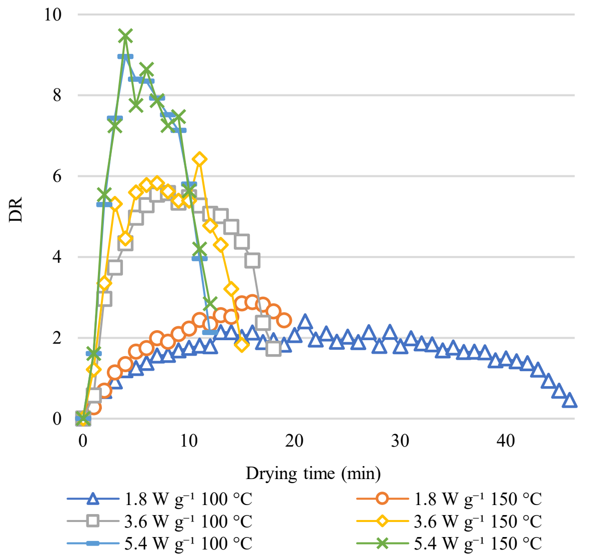

Fig. 4. Changing of DR with different microwave power densities and drying air temperatures

In the microwave and fan assisted hot air combination study, the highest drying rate with 9.47 g water/g dry matter.min at 5.4Wg^{-1}-150°C power density and temperature in foam dried samples. As can be understood from this, an increase in the drying rate of the foam dried samples was observed with the increase in power density and temperature.

During the drying of the kumquat samples with foam, drying processes performed at all power density and temperatures; mostly a decreasing rate of drying period was observed. Constant rate drying phase was observed in places.

In his study, Maskan [20] made experiments on drying bananas with 3 different methods: hot air, microwave and a combination of these two methods, and these methods were compared with each other. According to the results, it was determined that the drying rate increased with the increase of power level in microwave drying, drying with hot air after microwave drying increased the drying rate and shortened the drying time, and the products obtained as a result of this process were not different from other methods in terms of color and re-watering capacity.

Similar results were found in the drying of mango pulp foam [6], papaya pulp foam [8], pumpkin pulp foam [21] tomato pulp foam [22] and Cumbeba Pulp foam [23]. The drying rate obtained in kumquat drying studies depends on factors such as the drying method used, drying temperature, relative humidity, and thickness of the kumquat slices.

3.3 Mathematical modelling

The variation of the moisture content obtained during the drying of the foam-dried kumquat puree samples with different drying methods with the drying time was investigated as thirteen drying models. The drying coefficients, R^2, χ^2 and RMSE statistical parameters of the mathematical models applied to the drying curves are shown in Table 2, 3 and 4 for the combination of microwave, microwave and fan assisted hot air, respectively. Also, model constants are shown in Table 5

For both drying methods Kulcu et. al. model (unpublished) equation was determined as the best predictive equation depending on model choosing criteria.

As in many studies with various agricultural products, drying was done with microwave and convective drying methods using similar microwave power densities and similar temperatures in this study, and the experimental data obtained from the drying processes were converted into estimation data with the thin layer drying equations used in this study.

Table 2. Comparison of models according to model criterias at different 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**
Newton	0.0949	0.0093	0.9657	0.8939	0.1105	0.0136	0.9670	0.8742	0.1125	0.0152	0.9757	0.8713
Page	0.0095	9.46^{-05}	0.9990	0.9989	0.0118	0.0001	0.9986	0.9985	0.0089	9.54^{-05}	0.9992	0.9991
Modified Page	0.0081	7.14^{-05}	0.9992	0.9992	0.0107	0.0001	0.9988	0.9988	0.0088	0.0001	0.9992	0.9992
Logarithmic	0.0193	0.0004	0.9955	0.9956	0.0220	0.0005	0.9949	0.9950	0.0223	0.0006	0.9948	0.9949
Two Term	0.0231	0.0006	0.9941	0.9936	0.0288	0.0010	0.9922	0.9914	0.0248	0.0009	0.9942	0.9937
Verma et al.	0.0259	0.0007	0.9925	0.9920	0.0381	0.0017	0.9887	0.9850	0.0440	0.0025	0.9853	0.9802
Midilli et al.	0.0046	2.32^{-05}	0.9997	0.9997	0.0048	3.01^{-05}	0.9997	0.9997	0.0057	5.01^{-05}	0.9996	0.9996
Henderson and Pabis	0.0671	0.0049	0.9497	0.9469	0.0749	0.0071	0.9460	0.9423	0.0689	0.0071	0.9546	0.9517
Otsura et al.	0.0498	0.0026	0.9744	0.9707	0.0553	0.0034	0.9723	0.9685	0.0526	0.0033	0.9748	0.9718
Diffusion approximation	0.0259	0.0007	0.9925	0.9920	0.0338	0.0013	0.9891	0.9882	0.0306	0.0012	0.9911	0.9904
Jena&Das	0.0091	8.99^{-05}	0.9990	0.9990	0.0084	8.94^{-05}	0.9992	0.9992	0.0091	0.0001	0.9991	0.9991
Demir et al.	0.0193	0.0004	0.9955	0.9956	0.0220	0.0006	0.9949	0.9950	0.0223	0.0007	0.9948	0.9949
Kulcu et al.	0.0071	5.72^{-05}	0.9994	0.9994	0.0046	3.18^{-05}	0.9997	0.9997	0.0048	4.8^{-05}	0.9997	0.9997

Table 3. Comparison of models according to model criterias at different microwave power densities with FAHA 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**
Newton	0.0974	0.0099	0.9653	0.8954	0.1100	0.0136	0.9676	0.8756	0.0436	0.0023	0.9834	0.9701
Page	0.0150	0.0002	0.9977	0.9975	0.0139	0.0002	0.9981	0.9979	0.0261	0.0008	0.9897	0.9892
Modified Page	0.0124	0.0001	0.9983	0.9982	0.0125	0.0001	0.9984	0.9983	0.2264	0.0732	0.9581	0.1970
Logarithmic	0.0174	0.0003	0.9966	0.9966	0.0204	0.0005	0.9956	0.9957	0.0129	0.0002	0.9972	0.9973
Two Term	0.0282	0.0008	0.9919	0.9911	0.0308	0.0012	0.9911	0.9902	0.0134	0.0003	0.9972	0.9971
Verma et al.	0.0314	0.0010	0.9898	0.9891	0.0365	0.0016	0.9898	0.9862	0.0158	0.0003	0.9974	0.9960
Midilli et al.	0.0034	1.32^{-05}	0.9998	0.9998	0.0053	3.65^{-05}	0.9997	0.9997	0.0068	7.83^{-05}	0.9992	0.9992
Henderson and Pabis	0.0708	0.0054	0.9483	0.9447	0.0745	0.0071	0.9466	0.9428	0.0380	0.0024	0.9783	0.9773
Otsura et al.	0.0571	0.0034	0.9686	0.9640	0.0580	0.0037	0.9695	0.9654	0.0697	0.0060	0.9282	0.9238
Diffusion approximation	0.0314	0.0010	0.9898	0.9891	0.0354	0.0015	0.9881	0.9871	0.0249	0.0008	0.9904	0.9902
Jena&Das	0.0073	5.85^{-05}	0.9994	0.9994	0.0092	0.0001	0.9991	0.9991	0.0083	0.0001	0.9988	0.9989
Demir et al.	0.0174	0.0003	0.9966	0.9966	0.0204	0.0005	0.9956	0.9957	0.0129	0.0002	0.9972	0.9973
Kulcu et al.	0.0038	1.66^{-05}	0.9998	0.9998	0.0042	2.73^{-05}	0.9998	0.9998	0.0011	3.41^{-06}	0.9999	0.9999

Table 4. Comparison of models according to model criterias at different microwave power densities with FAHA 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**
Newton	0.1068	0.0120	0.9622	0.8811	0.1116	0.0143	0.9652	0.8695	0.0793	0.0088	0.9902	0.9246
Page	0.0129	0.0001	0.9984	0.9982	0.0133	0.0002	0.9982	0.9981	0.0111	0.0001	0.9985	0.9985
Modified Page	0.0110	0.0001	0.9987	0.9987	0.0118	0.0001	0.9985	0.9985	0.0061	6.67E-05	0.9995	0.9995
Logarithmic	0.0220	0.0005	0.9949	0.9949	0.0302	0.0011	0.9903	0.9904	0.0200	0.0007	0.9948	0.9951
Two Term	0.0301	0.0010	0.9914	0.9905	0.0285	0.0011	0.9920	0.9914	0.0105	0.0002	0.9986	0.9986
Verma et al.	0.0340	0.0012	0.9888	0.9879	0.0352	0.0015	0.9877	0.9869	0.0341	0.0020	0.9881	0.9860
Midilli et al.	0.0044	2.18^{-05}	0.9997	0.9997	0.0118	0.0001	0.9985	0.9985	0.0054	7^{-05}	0.9996	0.9996
Henderson and Pabis	0.0767	0.0065	0.9427	0.9386	0.0749	0.0076	0.9443	0.9411	0.0429	0.0043	0.9782	0.9778
Otsura et al.	0.0560	0.0033	0.9716	0.9672	0.0541	0.0033	0.9743	0.9693	0.0591	0.0048	0.9651	0.9581
Diffusion approximation	0.0340	0.0012	0.9888	0.9879	0.0353	0.0015	0.9876	0.9869	0.0200	0.0007	0.9951	0.9951
Jena&Das	0.0097	0.0001	0.9990	0.9990	0.0179	0.0004	0.9965	0.9966	0.0084	0.0001	0.9990	0.9991
Demir et al.	0.0220	0.0005	0.9949	0.9949	0.0302	0.0012	0.9903	0.9904	0.0200	0.0009	0.9948	0.9951
Kulcu et al.	0.0040	1.98^{-05}	0.9998	0.9998	0.0102	0.0001	0.9988	0.9988	0.0019	2.64^{-05}	0.9999	0.9999

Table 5. Model coefficients of chosen model

MODEL COEFFİCİENTS												
1.8 Wg^{-1}	a:	65.7697	b:	0.0772	k:	0.7020	n:	1.0117	c:	0.48906	d:	-0.41168
3.6 Wg^{-1}	a:	5353.167	b:	0.011409	k:	0.00436	n:	2.036254	c:	1.01673	d:	-0.08534
5.4 Wg^{-1}	a:	4.766828	b:	0.040608	k:	0.004542	n:	2.436731	c:	1.05513	d	-0.01561
1.8 Wg^{-1}-100°C	a:	0.428959	b:	-0.25269	k:	0.005909	n:	1.472441	c:	0.99477	d	-0.24718
3.6 Wg^{-1} -100°C	a:	1.242946	b:	0.416335	k:	0.001675	n:	2.392322	c:	1.0339	d:	-0.0609
5.4 Wg^{-1}-100°C	a:	23.87215	b:	-0.03657	k:	0.000362	n:	3.810705	c:	1.16744	d:	0.061255
1.8 Wg^{-1}-150°C	a:	1.050045	b:	2.159754	k:	0.001416	n:	1.953497	c:	1.0064	d:	-0.10463
3.6 Wg^{-1}-150°C	a:	0.933367	b:	0.302835	k:	0.001203	n:	2.832842	c:	1.0427	d:	0.046201
5.4 Wg^{-1}-150°C	a:	2.052668	b:	-0.01097	k:	0.00402	n:	3.356737	c:	1.22342	d:	0.062004

* For all experiments Kulcu et. al. model provides best fit.

3.4 Color

L*, a*, b*, C*, Hue angle, and ΔE values of fresh and dried kumquat fruit are given in the Table 6. The L*, a*, and b* values of fresh kumquat were determined as 66.27, 11.06, and 46.56, respectively. The L*, a*, b*, C*, Hue, and ΔE values of kumquat samples dried by different methods were determined in the ranges of 56.16-66.89, 11.06-19.51, 44.32-54.79, 47.66-57.36, and 8.66-12.01 respectively. Variance analysis results indicated significant ($P<0.05$) impact of microwave power density and temperatures on all color values. Foam drying's effect on color parameters was disregarded due to consistent use of the same foaming agent and stabilizer in mashed of kumquat samples.

Considering the results, a great change was observed for the L* value, which is the brightness indicator, with the change of microwave power additionally it can be said that the temperature has tiny effect. Increasing of microwave power reduces the L* value.

Table 6. Comparing the color parameters of drying methods

Drying Method	L	a	b	c	Hue	ΔE
Fresh	66.27^{a} (±0.78)	11.06^{f} (±0.28)	46.56^{d} (±0.70)	47.85^{d} (±0.72)	76.64^{a} (±0.24)	-
1.8 Wg^{-1}	63.55^{b} (±1.38)	19.51^{a} (±0.61)	53.4^{ab} (±1.79)	56.85^{ab} (±1.85)	69.92^{cd} (±0.38)	11.32^{ab} (±1.29)
1.8 Wg^{-1} 100 ºC	65.48^{ab} (±0.34)	19.38^{a} (±0.56)	53.98^{ab} (±0.80)	57.36^{ab} (±0.94)	70.25^{c} (±0.27)	11.19^{ab} (±0.91)
1.8 Wg^{-1} 150 ºC	66.84^{a} (±0.76)	18.91^{ab} (±0.71)	51.74^{bc} (±1.87)	55.09^{bc} (±1.99)	69.92^{cd} (±0.09)	9.48^{bc} (±1.69)
3.6 Wg^{-1}	66.89^{a} (±1.37)	18.64^{abc} (±0.66)	54.78^{a} (±0.88)	57.87^{a} (±0.99)	71.21^{b} (±0.48)	11.26^{ab} (±1.02)
3.6 Wg^{-1} 100 ºC	61.41^{c} (±0.72)	17.89^{bcde} (±0.80)	44.9^{d} (±1.43)	48.33^{d} (±1.62)	68.28^{g} (±0.26)	8.66^{c} (±0.24)
3.6 Wg^{-1} 150 ºC	63.74^{b} (±1.59)	18.47^{abcd} (±0.64)	49.66^{c} (±2.67)	52.98^{c} (±2.71)	69.58^{de} (±0.44)	8.74^{c} (±1.30)
5.4 Wg^{-1}	56.23^{d} (±1.62)	17.52^{de} (±0.32)	44.32^{d} (±0.58)	47.66^{d} (±0.58)	68.43^{fg} (±0.37)	12.17^{a} (±1.47)
5.4 Wg^{-1} 100 ºC	56.73^{d} (±0.92)	17.58^{cde} (±0.26)	44.78^{d} (±0.64)	48.11^{d} (±0.66)	68.57^{fg} (±0.22)	11.71^{a} (±0.74)
5.4 Wg^{-1} 150 ºC	56.16^{d} (±1.24)	17.17^{e} (±0.77)	44.77^{d} (±1.15)	47.95^{d} (±1.34)	69.02^{ef} (±0.42)	12.01^{a} (±1.11)

Parallel to these results, the same results are observed at a* and b* values. By inference from here, parallelism has been observed between the L values and the a and b values depending on trials. With increasing of a* and b* values increase the darkening of the samples. According to this evaluation, it can be said that darkening occurred at higher power densities.

Chroma refers to the intensity and clarity of color [24]. Fresh one has the lowest C* value. It can be considered as the difference of puree and powder product. Comparing trails with fresh one, powdering process increases the homogeneity and product becomes clearer. This clarity makes an impact on customers choices.

In a study, it was determined that the saturation value (chroma) of gac fruit powders dried with foam drying increased with the increase in drying temperature, and the powder product dried at high temperature had the highest saturation value [25], however this kind of correlation didn't observe in this study.

In ΔE values, no change was observed with the change of microwave power densities. In the combination method, it was determined that a serious decrease in ΔE values occurred with the use of high microwave power density and high temperatures together. Similar results were obtained in drying studies conducted by some researchers [26, 27].

3.5 Specific energy consumption

SEC values have determined for all power densities and combinations (Fig. 5). Energy consumption values ranged between 1.94 to 10.60 Wh g^{-1}, so variety is very large. There is a huge gap between microwave densities and FAHA. Even the lowest consumption of the combination was higher than the highest consumption of microwave power density.

SEC values decreased with the increase of the applied microwave power densities in the microwave drying method. On the contrary, it was determined that the specific energy consumption increased with the increase of the applied drying air temperature in the combination drying method, (except 1.8 Wh g^{-1}).

The drying times of the samples are highly effective on the specific energy consumption. In addition, considering drying times there is a large change on lower power densities. As the power density increases, the variation in drying time decreases. Considering the best efficiency for drying at 5.4 Wh g^{-1} occurred. In addition, at this power density requires shorter drying time.

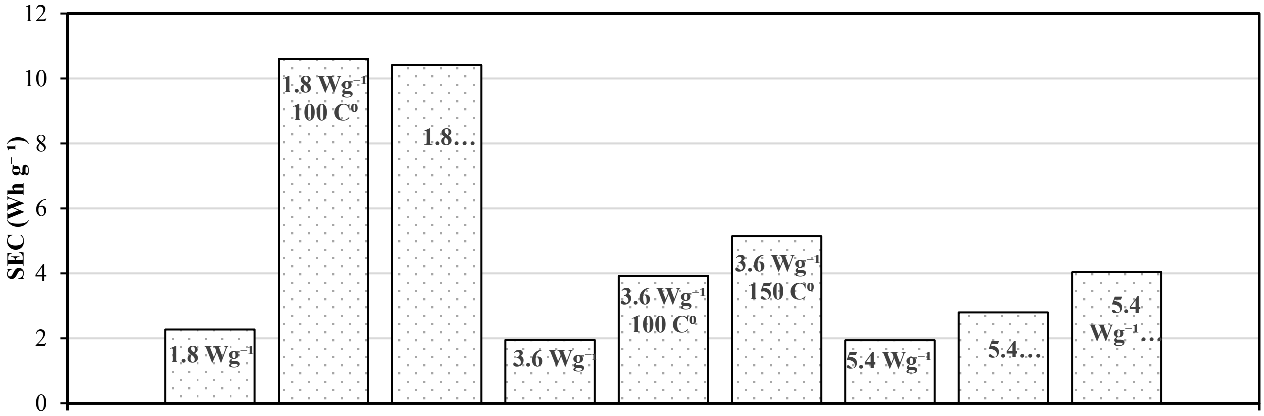

Fig. 5. Comparing the specific energy consumptions (SEC) of drying methods.

4. Conclusions

Kumquat was dried as a puree using a combination of microwave drying and microwave-fan assisted hot air drying. Whether there is a difference between drying methods was also examined within the scope of the study. Accordingly, differences were observed in terms of drying time, powder formation by grinding the dried final product, and final product color. Although the high microwave and temperature combination drying method was advantageous in terms of time compared to other drying methods, it caused darkening of the products in some conditions. The purpose of microwave and fan assisted hot air combination drying is to improve drying efficiency by trying several drying processes together in a single drying process. It is considered as an advantage to try to improve the product quality in trials with combination drying studies.

References

1. F. Jaliliantabar, A.N. Lorestani, R. Gholami. Int. Agrophys, **27**, 107-109 (2013)
2. E.S. Sadek, D.P. Makris, P. Kefalas. Plant Foods Hum Nutr **64**, 297–302 (2009)
3. O.M. Al Zoubi, N. Mohd Noor. Australian Journal of Crop Science, **7,** 6, 758–762 (2013)
4. E. Abbasi, M. Azizpour. LWT - Food Science and Technology, Volume **68**, 105-110, ISSN 0023-6438 (2016)
5. R. Thuwapanichayanan, et. al. Journal of Food Engineering, **86**, 573–583 (2007)
6. P. Rajkumar, et. al. Journal of Food Engineering, **79**, 1452–1459 (2007)
7. Q. Fardiyah, et al. *The Effect of Temperature and Concentration of Foaming Agent to the β-Carotene Content in Product Derived from Carrots* IOP Conf. Ser.: Mater. Sci. Eng. 299 (2018)
8. P. Kandasamy, et al. Food Science and Quality Management, **9**, 17–27 (2012)
9. [AOAC] Assn. of Official Analytical Chemists. *Coffee and tea.* In: Official methods of analysis. 17th ed. Gaithersburg , Md. : AOAC (2000)
10 K. Sacilik, A.K. Elicin. Journal of Food Engineering, **73**, 3, 281-289, ISSN 0260-8774 (2006)
11. İ. Doymaz, N. Tugrul, M. Pala. Journal of Food Engineering, **77**, 3, 559-565, ISSN 0260-8774 (2006)
12. S. Minaei, A. Motevali, E. Ahmadi, H. Azizi. J.Agric.Sci.Technologies (2012)
13. S. Naderinezhad, N. Etesami, A. Poormalek Najafabady, M. Ghasemi Falavarjani. Food Sci Nutr., **4**, 110-118 (2016)
14. M. Maskan. Journal of Food Engineering **48**, 2, 169-175 (2001)
15. H.D. Voss. Hort. Science, **27**,12, 129-145 (1992)
16. Y. Soysal. Biosystems Engineering, **89**, 167-173 (2004)
17. P.F.R. Guiné, M.J. Barroca. Food and Bioproducts Processing, 90, 1, 58-63, ISSN 0960-3085 (2012)
18. A. Unadi, R.J. Fuller, R.H. Macmillan. Drying Technology, **20**, 7, 1407-1425 (2002)
19. J. Varith, P. Dijkanarukkul, A. Achariyaviriya, S. Achariyaviriya. Journal of Food Engineering, **81,** 2, 459-468, ISSN 0260-8774 (2007)
20. M. Maskan. Journal of Food Engineering, 44, 2, 71-78, ISSN 0260-8774 (2000)
21. S. Das, et al., Int. J. Food Nutr. Sci. 4, 50–55 (2015)
22. M. Sramek, et al., Journal of Food Science, **80**, E1755–E1762 (2015)
23. Diógenes, A.M.G., et al. Foods, 11, 1751 (2022)
24. R.E. Wrolstad, R.W. Durst, J. Lee. Trends in Food Science & Technology, **16,** 9, 423-428, ISSN 0924-2244 (2005)
25. T. Auisakchaiyoung, et al. International Food Research Journal **22**, 5, 2025-2031 (2015)
26. E. Horuz, et al. Journal of Food Science and Technology, **52**, 285–293 (2015)
27. C. Kumar, et al. Journal of Food Engineering, **121**, 48–57 (2014)