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RESEARCH

Assessments of *Gypsophila* used as foaming agent on kinetics, energy consumption, and biochemical properties of tangerine flakes processed by microwave-assisted foam-mat drying

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Abstract

Many agents are used as foaming agents in foam drying studies. The effect of *Gypsophila* extract used as a foaming agent was investigated. In this study, the effects of *Gypsophila* extract ratios used as a foaming agent and microwave power (MD) values were examined. Moisture rate (MR), drying rate (DR), effective moisture diffusion (D_{eff}), specific moisture extraction rate (SMER), specific energy consumption (SEC), total phenol content (TPC), total flavonoid content (TF), total antioxidant content (TAC), and foaming properties of the drying processes and produced flakes were investigated. The DR values of the drying processes ranged between 8.10 and 62×10^{-2} g moisture/g dry matter.min. The D_{eff} values of the drying processes ranged between 9.36×10^{-7}– 7.13×10^{-6} m^2/s. The SMER and SEC values of the drying processes ranged between 0.011 and 9.24 kg/kWh and 32.84–118.30 kWh/kg, respectively. It was found that foaming agent ratios and microwave power values affected the color and foaming properties. The lowest total color change (ΔE) was determined in the 900 W −15% process. The highest overflow was specified in the 5% foaming agent. There was no significant difference between the porosity values of the foams ($p > 0.05$). The TPC, TF, and TAC properties of the dried samples changed between 3822.2 and 9077.2 µg GAE g^{-1}, 538.52–947.78 mg KE L^{-1}, and 15.03–29.18 µmol TE g^{-1}, respectively.

1 Introduction

The tangerine (*Citrus reticulata)* fruit belongs to the Ruataceae family *of* citrus fruits and originates in Southeast Asia. This fruit, which spread to different parts of the world over time, is among the important commercial products of the Mediterranean today [1]. Turkey produced approximately 4.7 million tons of citrus fruits in 2022. The majority of production is provided from the Aegean and Mediterranean Regions. Tangerine produce 87% and total production takes place in the Mediterranean Region [2]. Tangerine fruit is an important food source for health as it contains valuable nutritional ingredients such as vitamins A, B, C, potassium, phosphorus, calcium, minerals, pectin, and folic acid. However, it is used as dietary fiber and contains many phytochemicals [3].

The drying process is a heat-mass transfer event that occurs simultaneously in the product, in which the reproduction of microbial organisms such as fungi, mold, and yeast is prevented by removing a large part of the water amount and reducing the water activity of the product by applying it to store agricultural products with high moisture content for a long time without spoiling [4]. The drying process is a preservation method that is cheaper than many other methods, requires less labor, and less equipment [5]. Many different methods are used in the drying process. The oldest method used is open drying under the sun. Although it is a simple method, the fact that the products are exposed brings negativities such as dust, insects, birds, rain, and wind. In addition, the open drying method requires a large drying area and a long drying time. For this reason, it is extremely important to carry out the drying process using controlled methods. The success of the drying process depends on the right choice of dryer in terms of both product quality and the profitability of the business [6]. As an alternative to open

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drying, dryers working with heated air have been developed [7]. Apart from these methods, microwave (*MD*) drying is also used in fruit and vegetable drying [8]. In the microwave drying method, it directly targets the water molecules in the material and the heat is generated directly in the product. The moisture in the product heats up and evaporates in a short time and the moisture transfer is from the inside to the outside due to the internal external vapor pressure difference in the environment [9]. Foam drying is the method in which liquid or semi-liquid/solid foods are dried by adding a foaming agent and foam stabilizer and the foam is obtained as a result of the mixture in the form of a thin layer with the appropriate drying method [10]. Foam drying method is a method used especially for drying sensitive foods with viscous structure [11]. In the literature, it has been reported that foam drying has positive results in studies on fig fruit (*Ficus carica* L.) [12], ripe banana [13], and melon (*Cucumis melo*) [14]. The gas bubbles in the foam are porous and provide a large surface area. This, in turn, increases the drying rate and reduces the drying time [12]. This is the foaming agent that allows the bubble structure to form. In the literature [15], used carboxymethyl cellulose, whey protein powder, and soy protein isolate as some foaming agents used in the drying processes of fruits from the *citrus* family. In studies carried out using the foam drying method, these types of industrial foam formers are generally used. In the literature, there is the use of various foaming agents to obtain foam. However, there has not been any study investigating the effectiveness of *Gypsophila* extract, which is used as a foaming agent, in drying tangerine juice. In this respect, the originality of the study has been demonstrated. *Gypsophila* bicolar contains 2–21% saponins [16, 17]. In the study conducted by [18], it was observed that the saponins obtained from hyssop remained stable during processing (extraction, concentration, etc.) [16]. Due to its high saponin content, it is aimed to be used as a foaming agent that helps foaming.

In this study, the effect of *Gypsophila* extract, which is used as a foaming agent, on the kinetics of tangerine flakes processed by microwave-assisted microwave drying was investigated.

2 Materials and methods

2.1 Raw material and chemical agents

Fresh tangerine fruits used to produce flakes were purchased from the market in Tokat/Turkey. The fruit samples were stored at +4±0.5 ºC in refrigerator conditions until the end of the study. Maltodextrin ($C_{12}H_{22}O_{11}$) (Parmor-Turkıye) was used as a carrier agent. *Gypsophila* extract used as a foaming agent was obtained in the Biosystems Engineering laboratory. All chemicals required for bioactive analyses were obtained from Merck KGaA (Germany).

2.2 Sample Preparation

Fresh tangerine fruit purees firstly were thoroughly washed with tap water, they were kept in an open environment for a while to dry their rough water. In this study, 20% dilution with distilled water was made by taking into account the method [19], for puree preparation. The puree was processed with an ARÇELİK brand, TB 9285 CI model, 220–240 V, 50–60 Hz, 800 W glass blender for 30 s. Firstly, *Gypsophila* powder was processed under a magnetic stirrer for 30 min. The obtained mixture was filtered and extract was obtained. The prepared *Gypsophila* extract was stored at +4±0.5 ºC for 2 days. The extract was renewed every.

2 days. Samples weighing 100–120 g in total were used in the sample plates. *Gypsophila* extract was added at rates of 5, 10, and 15% of the sample batch. To foam the puree, the *Gypsophila* extract was added separately at rates of 5, 10, and 15%. The 1% maltodextrin was added to the prepared mixture (tangerine juice + *Gypsophila* extract) in to stabilize it. The mixture (tangerine juice + *Gypsophila* extract + maltodextrin) was mixed in a glass blender for 60 s.

2.3 Foaming properties

Overrun, porosity, expansion, density, and drainage-stability foaming properties of the foam obtained from tangerine fruit juice were investigated.

Overrun The overrun property of the foam was calculated using Eq. 1 [20].

$$Overrun\ (\%) = \frac{\frac{1}{p_{foam}} - \frac{1}{p_{pulp}}}{\frac{1}{p_{pulp}}} \times 100 \tag{1}$$

Here: p_{foam}: The density of the foam (kg/m^3), p_{pulp}: The density of the pulp (kg/m^3).

Porosity The porosity property of the foam was calculated using Eq. 2 [33].

$$\varnothing = 1 - \frac{p_{foam}}{p_{pulp}} \tag{2}$$

Here: *pfoam*: The density of the foam (kg/m^3), *ppulp*: The density of the pulp (kg/m^3).

Expansion The expansion property of the foam was calculated using Eq. 3 [41].

$$\% = \frac{V_1 - V_0}{V_0} \times 100 \tag{3}$$

Here V_1: Volume of pulp (m^3), $V0$: Volume of foam (m^3).

Density The density property of the foam was calculated using Eq. ^{3} 4 [43].

$$Density = \frac{Foam\ weight\ (g)}{Foam\ volume\ (cm^3)} \tag{4}$$

Drainage-stability The density property of the foam was calculated using Eq. 5 [41].

$$\% = \frac{V_0 - V_d}{V_0} x\ 100 \tag{5}$$

Here V_0: Volume of foam (m^3), V_d: Volume of extinguished foam as liquid (m^3).

2.4 Drying processes

The prepared fresh tangerine purees (tangerine juice + *Gypsophila* extract + maltodextrin) were dried by microwave oven (MD).

Microwave drying MD Vestel brand MD-GD23 model microwave oven is used. The microwave oven has a total output power of 900 W and its dimensions are height × width × depth, respectively, 305 mm × 508 mm × 385 mm. The products were dried on a rotating glass dish in the MD. Fresh tangerine purees were dried at 360, 540, 720, and 900 W drying conditions. Approximately 100–120 g of mixture samples were used in the drying process. These samples were dried to < 5% (w.b.) until the weight change became constant. Weight change was monitored using a precision balance to determine the amount of moisture removed from the drying samples and to use it in other drying kinetics properties.

2.5 Drying Rate DR

Equation 6 was used to calculate the drying rate of tangerine flakes [21].

$$\frac{M_t - M_{(t+dt)}}{dt} \tag{6}$$

Here: M_t: Moisture content at time t (g moisture/g dry matter), t: Minutes, DR: Drying rate (g moisture/g dry matter).

2.6 Moisture Rate MR

Moisture ratio (MR) is expressed as the ratio of the amount of moisture removed from the dried material per unit of time. Equation 7 was used to determine the rates of moisture removed from the tangerine flakes [22].

$$\mathrm{MR} = \frac{M - M_e}{M_0 - M_e} \tag{7}$$

Here: MR: Moisture rate, M: The instant moisture content of the product (g moisture/g dry matter), M_e: The equilibrium moisture content of the product (g moisture/g dry matter), M_o: The initial moisture content of the product (g moisture/g dry matter).

2.7 Effective moisture diffusion value Deff

The average foam property of the dried foam was measured as 13.82 mm. The porosity, homogeneity, and distribution effect of the foams in each parallel dried plate in the oven were considered unimportant. Equations 8–9 were used to determine the effective moisture diffusion of tangerine flakes [23, 24].

$$MR = \frac{M - M_e}{M_{0-} M_e} = \frac{8}{\pi}\sum{}_{n=0} \frac{1}{(2n+1)^2}\, exp\left[(2n+1)^2\, \frac{2}{4}\frac{D_{fft}}{L^2}\right] \tag{8}$$

$$In\ MR = In\frac{8}{2} - \frac{{}^2D_{efft}}{4L^2} \tag{9}$$

Here: D_{eff}: Effective diffusion value (m^2/s), L: Half of the slice thickness (m) of the product. t: Indicates the drying time of the product.

2.8 Total energy consumption value

Polaxtor brand PLX-15,366 model energy analyzer (± 0.02 kWh) was used to measure the energy consumption values of drying processes tangerine flakes.

Specific Moisture Extraction Rate SMER Equation 10 was used to calculate the specific moisture extraction rates (SMER) of drying processes for tangerine flakes [25].

$$SMER = \frac{Evaporating\ moisture\ (kg)}{Consumption\ energy\ (kWh)} \tag{10}$$

Here: SMER: Specific moisture extraction rate (kg/kWh).

Specific Energy Consumption SEC Equation 11 was used to calculate the specific energy consumption (kWh) of the drying processes of tangerine flakes [26].

$$SEC = \frac{E_t}{m_w} \tag{11}$$

Here: *SEC*: Specific energy consumption (kWh/kg moisture), E_t: Total consumed energy (kWh), m_w: The amount of moisture removed (kg).

2.9 Color value

CR400 model/Japan color measuring device was used to measure the brightness *L*, red/green *a*, and yellow/blue *b* values of tangerine flakes and puree. The measured values are laboratory measurement values and chroma and total color change values were calculated by using Eqs. 12 and 13. While the chroma value indicates the color tone of the tangerine flakes and puree, low-quality products are calculated for pale products, while high values are calculated. The total color change value shows the total change of color pigments that are decomposed by heat (non-enzymatic) in drying processes. The calculated color values are more important in terms of their commercial value and decision-making for the consumer. The following equations were used to calculate these values [27, 28].

$$Chroma \quad C = (a^2 + b^2)^{1/2} \tag{12}$$

$$Total\ color\ diffrance \quad \Delta E = \sqrt{(L - L*)^2 + (a - a*)^2 + (b - b*)^2} \tag{13}$$

Here: The *a* and *b* values show the redness and yellowness values of tangerine flakes and puree. *C*: Chroma, *ΔE*: Total color diffrance.

2.10 Bioactive analyzes

Total Phenolic Content TPC *TPC* was determined using the method of [29]. Mandarin samples (1 g) were extracted with a buffer (acetone, water, acetic acid; 70:29.5:0.5 v/v) over three days. The extract was mixed with Folin-Ciocalteu reagent, water, and 7% sodium carbonate, then incubated at room temperature for 2 h. Absorbance was measured at 750 nm using a UV-vis spectrophotometer (T60U, PG Instruments). Gallic acid served as the standard, and results are expressed as µg GAE g^{-1} dry weight (dw).

Total Flavonoid Content TF TF content was analyzed following the method of [30]. To 1 mL of extract, 5 mL distilled water and 0.3 mL of 5% $NaNO_2$ were added. After 5 min, 0.3 mL of 10% $AlCl_3$ was incorporated, followed by 2 mL of 1 M NaOH after another 5 min. The mixture was diluted to 10 mL with distilled water, and absorbance was immediately measured at 510 nm. Results are expressed as mg catechin equivalent (KE) L^{-1} dry weight (dw).

Total Antioxidant Activity TAC TAC was measured using the ABTS assay as described by [31]. A 7 mmol/L ABTS solution prepared with acetate buffer and potassium persulfate was diluted with 20 mM sodium acetate buffer (pH 4.5) to achieve an absorbance of 0.700 ± 0.01 at 734 nm. For analysis, 2.95 mL $ABTS^+$ solution was mixed with 50 µL fruit pulp, incubated in the dark at room temperature for 10 min, and absorbance was measured at 734 nm. Results are reported as µmol Trolox Equivalent (TE) g^{-1} dry weight (dw).

2.11 Statistical analysis

SigmaPlot10 program was used to create the drying kinetics of the dried samples ($p < 0.05$). Duncan's multiple comparison test ($p < 0.05$) was performed in the SPSS17 program to statistically evaluate the findings obtained within the scope of the study.

3 Results and discussion

3.1 Moisture and drying rate MR-DR

MD power values and drying kinetic curves of tangerine puree evaluated with the help of foam drying are given in Fig. 1.

MD power values and *Gypsophila* extract (5, 10, and 15%) used as a foaming agent affected the moisture and drying rate values of tangerine puree. Tangerine purees were dried at microwave power values of 360, 540, 720, and 900 W, respectively. The drying time of the drying processes decreased with the increase of microwave energy [32]. This is because the increase in *MD* power value causes more heat generation in the product. The proportions of *Gypsophila* extract used as a foaming agent had different effects on the drying time of tangerine puree [33]. found that the presence of a foaming agent decreased the drying time of the product in the drying processes. In this study, an inverse relationship was found when compared with the findings in the literature. This is because the evaporation resistance of *Gypsophila* extract is stronger than the evaporation resistance of moisture in the puree. This situation led to an extension of the drying time. For this reason, it is recommended to use small proportions of *Gypsophila* extract for further

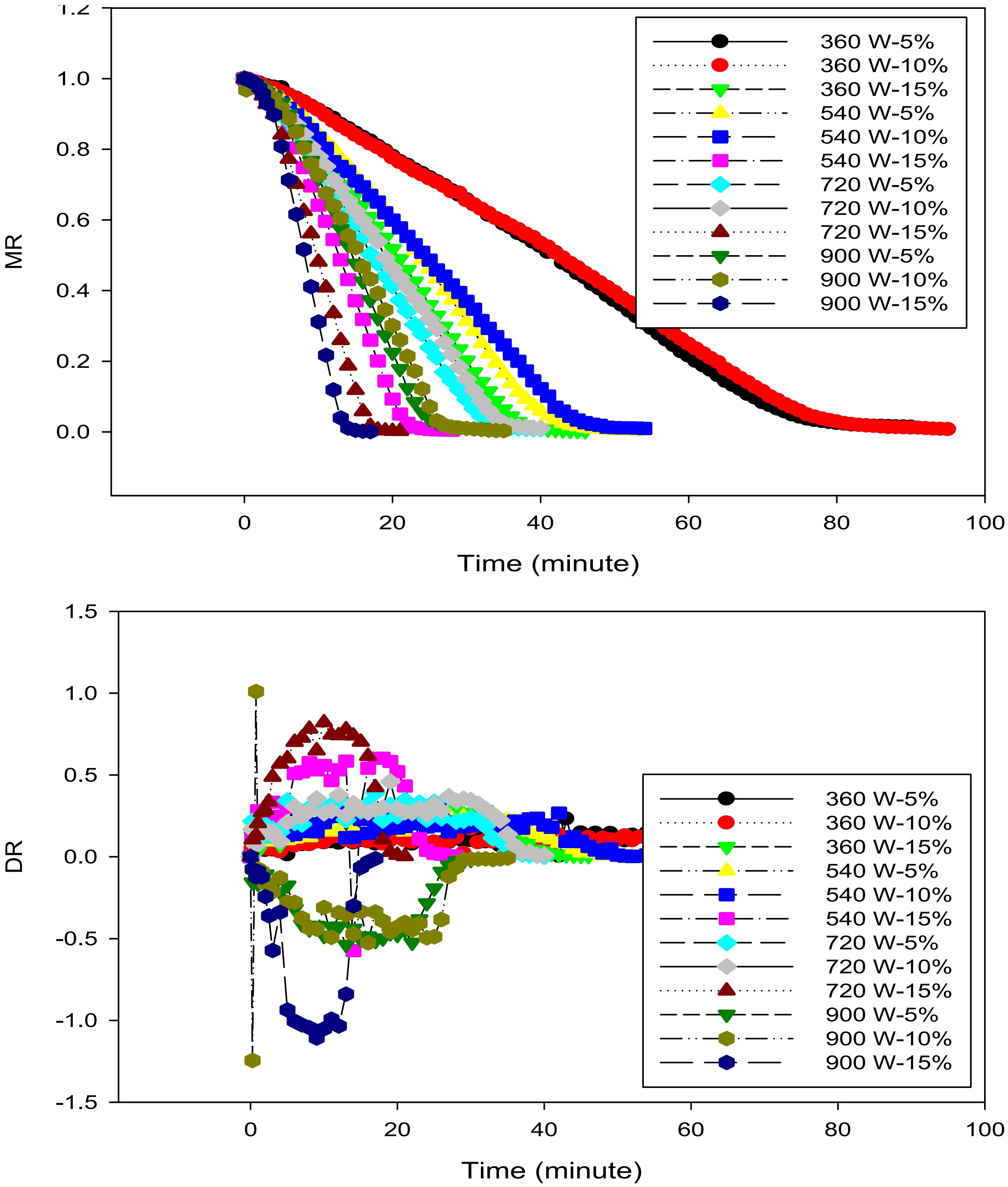

Fig. 1 MR *and* DR *curves of* drying processes

studies. When the *Gypsophila* extract ratio increased from 10 to 15%, the drying time of the material decreased. This is because *Gypsophila* extract foamed the material more and increased the active surface in contact with heat. At the same time, it provided an increase in the *MR* ratio. It led to a decrease in the drying time. This supports the findings in the literature given above. The DR curves of the tangerine puree increased rapidly at the beginning and then gradually decreased. It was found to be similar to the curves obtained in the studies in the literature. The average *DR* values of the tangerine puree varied between 8.10 and 62×10^{-2} g moisture/g dry matter [34]. The *DR* values of the drying processes increased with the increase in the *MD* power values. This is because the increase in the *MD* power values caused higher heat in the product. This situation positively affected the *DR* ratio of the tangerine puree. In the study where orange fruit slices were examined at 200, 400, 600, and 800 W power values, it was reported that *DR* values varied between 2.00 and 28.86×10^{-2} g moisture/g dry matter. min and increased at high *MD* power values [35]. found that as drying progressed, drying rates decreased as resistance to moisture decreased as the moisture content in the foam decreased. The ratios of *gypsophila extract* affected the *DR* ratios of tangerine puree at different levels. While the foaming agent used at *MD* 360 and 900 W power values and in the range of 5–10% decreased the *DR* rates of the material, the *DR* rate increased when used in the range of 10–15%. The reason for this is that at 360 W power value, the drying time of the product takes longer than the others, so the stability of the foam decreases in the range of 5–10% and therefore the *DR* rate decreases. Due to the high temperature-pressure difference effect in the material at 900 W power value, the stability of the foam decreases and the *DR* rate decreases. The *DR* ratios of the foaming agent material used at *MD* 540 and 720 W power values and in the range of 5–15% have increased continuously. The reason for this is that the amount of heat generated in the material at 540 and 720 W power values and the moderate heat exposure times did not significantly adversely affect the stability of the *Gypsophila* foam extract. This situation has continuously increased the *DR* rate of tangerine puree in the range of 5–15%.

3.2 Effective moisture diffusion

Effective moisture diffusion values are given in Table 1.

Table 1 Effective moisture diffusion-activation energy values

MD Power	Foaming agent ratio	D_{eff} (m^2/s)	$d_{ef}f$ R^2
360 W	5%	9.01×10^{-7}	0.8641
	10%	9.36×10^{-7}	0.8475
	15%	2.27×10^{-6}	0.8157
540 W	5%	2.00×10^{-6}	0.8369
	10%	1.59×10^{-6}	0.8459
	15%	4.03×10^{-6}	0.8580
720 W	5%	2.28×10^{-6}	0.8626
	10%	1.98×10^{-6}	0.8180
	15%	5.43×10^{-6}	0.8248
900 W	5%	2.87×10^{-6}	0.8879
	10%	3.08×10^{-6}	0.8464
	15%	7.13×10^{-6}	0.7816

* MD: Normal microwave dryer

MD power values affected the effective moisture diffusion values of tangerine puree [36]. According to the MD 360, 540, 720, and 900 W power values determined in the study, the effective moisture diffusion values varied between $2.27\times10^{-6}-9.36\times10^{-7}$, $1.59–4.03\times10^{-6}$, $1.98–5.43\times10^{-6}$, $2.87–7.13\times10^{-6}$ m^2/s, respectively. The increase in microwave power values increased the effective moisture diffusion values [11]. found in their study that the effective moisture diffusion values varied between 5.47×10^{-7} -2.27×10^{-6} m^2/s. The reason why the values obtained in the literature are lower than the values obtained in this study is the difference in the material and/or foaming agent used. In this study, the increase in the foaming agent also had a positive effect on effective moisture diffusion. However, the foaming agent used at 15% showed an increase in effective moisture diffusion. The foam layer formed in the material broke the foam resistance due to high temperature and caused collapse [11].

3.3 SMER and SEC

The energy consumption curves of the tangerine puree evaluated with the help of *MD* power values and foam drying are given in Fig. 2.

It was observed that the energy consumption values of tangerine puree were affected by *MD* power values (360, 540, 720, and 900 W) and foaming agent ratios (5, 10, and 15%). Total energy consumption decreased with the increase in *MD* power value [37]. The total energy consumption of dried tangerine puree varied between 0.346 and 0.905 kWh according to 360, 540, 720, and 900 W power values. *SMER* values varied between 0.010922 and 9.243771 kg/kWh according to *MD* power values (360, 540, 720, and 900 W). *SEC* values of drying processes were found to vary between 32.84 and 118.30. The drying efficiency of microwave drying methods is higher than other drying systems [38]. In the microwave-assisted orange drying study conducted by [39]Taşova (2024), the SMER value was in the range of 0.0019–0.089 kg/kWh and the SEC values were in the range of 11.29–538.80 kWh/kg. When the values were compared, the tangerine puree was removed with less energy. In this study, energy consumption was affected by the increase in foaming agents [40]. With the increase in *gypsophila* extract, energy consumption has decreased. This is thought to be related to foaming capacity.

3.4 Color values

The color values of tangerine puree are given in Table 2.

According to the brightness *L* value of the fresh product, the drying power values of the dried tangerine puree with MD support could not be preserved statistically at

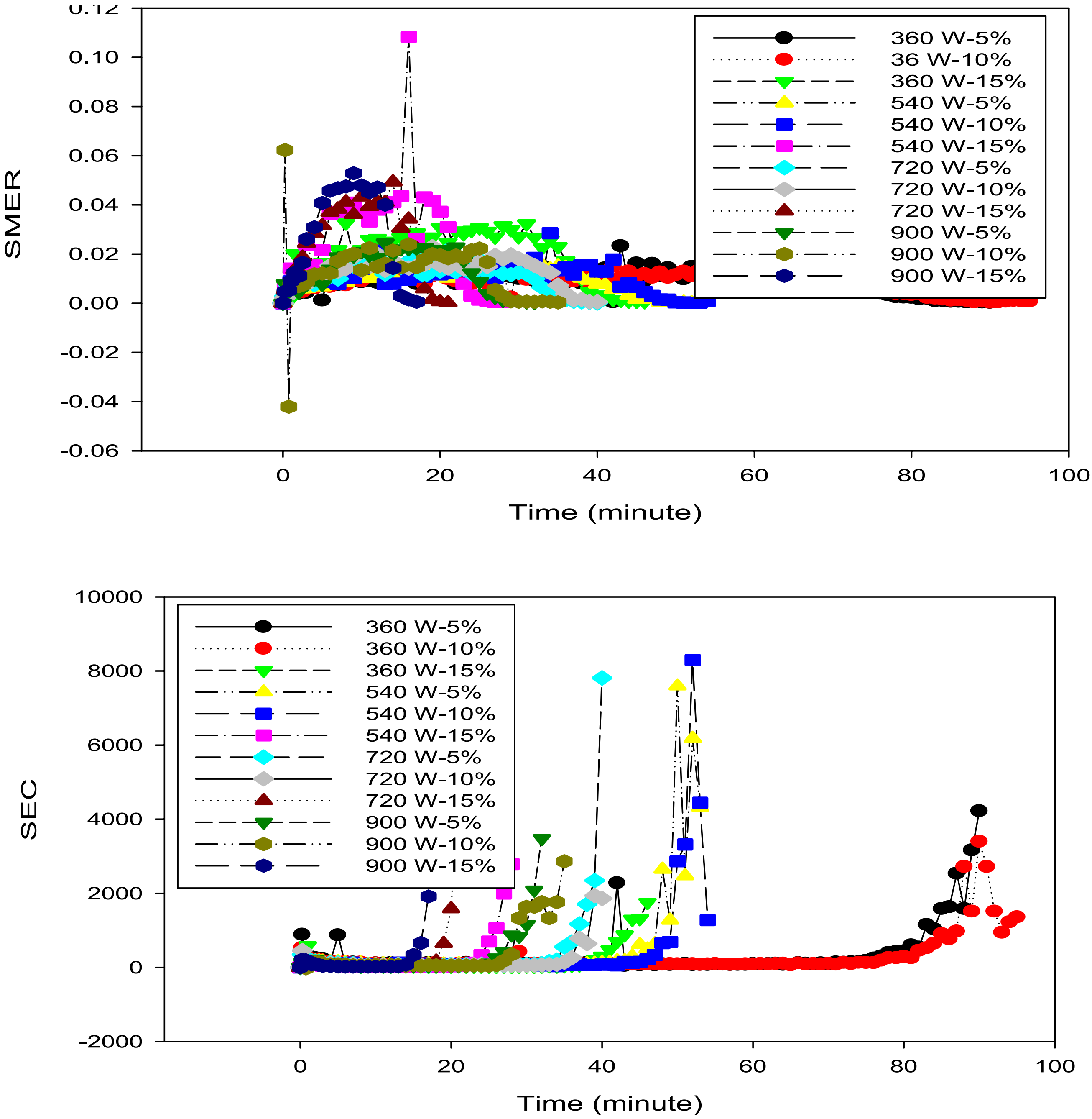

Fig. 2 Energy consumption values

some values. The reason for this situation is that the MD energy breaks down the whiteness pigment of the product and/or causes non-enzymatic darkening [34]. stated that the L values increased compared to the fresh product in the foam drying study they conducted with orange fruit. This is thought to be due to the effect of the foaming agent and/or drying conditions. In the study, there was no statistically significant difference compared to the fresh product at 540 W-15% a foaming agent, 720 W 10%–5%, and 900 W 15% foaming agent rates. The increase in the carrier agent rate at 360 W increased the L value. In other methods, the L value decreased with the increase in the foaming agent rate. Here, the effect of the foaming agent acted as a barrier against heat. In addition to the increase in the foaming agent, the increase in the MD power values caused high temperatures. This caused the product to caramelize and darken. According to the red color feature of the fresh product, the samples dried under MD power values could not preserve the red color value. It is thought that this is due to the increase in the density of the red color pigments

Table 2 Color values

MD Power	Foaming agent rates	L	a	b	C	ΔE
Fresh		46.61 ± 3.13de	1.91 ± 0.88e	12.64 ± 1.91e	12.80 ± 2.00f	-
360 W	5%	38.98 ± 7.45 g	8.40 ± 3.01c	21.25 ± 11.55de	23.06 ± 11.47	19.01 ± 3.18b
	10%	42.13 ± 6.07 fg	9.07 ± 1.73c	27.15 ± 8.00abc	28.67 ± 8.03bc	18.78 ± 4.24b
	15%	51.05 ± 1.43abc	10.63 ± 1.18b	29.65 ± 2.86a	31.50 ± 3.03ab	19.90 ± 3.90ab
540 W	5%	53.24 ± 1.42a	12.24 ± 0.51a	32.50 ± 1.82a	34.73 ± 1.68a	23.55 ± 2.18a
	10%	52.27 ± 1.75ab	12.26 ± 0.78a	32.80 ± 3.83a	35.03 ± 3.68a	23.79 ± 3.86a
	15%	46.92 ± 5.57cde	7.84 ± 0.95c	27.89 ± 5.40ab	28.99 ± 5.40bc	18.08 ± 3.78b
720 W	5%	47.52 ± 5.76cde	7.94 ± 2.47c	20.56 ± 8.28de	22.07 ± 8.28de	12.83 ± 5.29 cd
	10%	45.39 ± 3.51def	8.08 ± 2.09c	21.10 ± 5.47de	22.65 ± 5.53de	11.89 ± 5.43 cd
	15%	53.10 ± 3.19a	10.88 ± 0.74ab	31.03 ± 3.27a	32.88 ± 3.28ab	21.70 ± 4.97ab
900 W	5%	52.20 ± 4.84ab	6.42 ± 0.98d	23.90 ± 6.46bcd	24.77 ± 6.46 cd	14.12 ± 7.26c
	10%	48.44 ± 4.53bcd	9.13 ± 1.48c	27.79 ± 4.73cde	23.64 ± 4.90cde	13.85 ± 4.50c
	15%	43.57 ± 2.41ef	8.72 ± 0.87c	16.14 ± 2.59ef	18.35 ± 2.34e	9.55 ± 2.34d

** MD: Normal microwave dryer, L: Brightness, a: Red, b: Yellow, C: Chroma* Lettering should be evaluated separately for each column according to the significance level ($p < 0.05$)

Table 3 Foaming properties

Foaming agent rates	Overrun (%)	Porosity (kg/m^3)	Expansion (%)	Density (g/cm^3)	Drainage (%)
% 5	372.34 ± 61.54a	0.7634 ± 0.006b	0.6825 ± 0.04a	0.2142 ± 0.03a	68.19 ± 1.45a
% 10	307.75 ± 48.6a	0.7242 ± 0.02c	0.6224 ± 0.02a	0.2477 ± 0.03a	78.08 ± 16.11a
% 15	335.68 ± 77.3a	0.8163 ± 0.004a	0.6723 ± 0.03a	0.2345 ± 0.04a	75.42 ± 1.03a

as the moisture is removed from the foam/it dries [41]., it was observed that the dried products decreased brightness and redness compared to the fresh product. Increasing *MD* power values could not statistically maintain the color value in the jaundice b value compared to fresh. Fresh product yellowness *b* color value 360 W 5% foaming agent value, 720 W 5–10% foaming agent value, 900 W 10–15% foaming agent value. The increase in the value of the foaming agent did not affect the maintenance of the jaundice b value [42]. stated that in their study of mango drying with the effect of different foaming agents, the yellowness b value of foaming agents significantly affected the b value, but temperature alone did not have an effect *on* the b value. The effect of *MD* power values could not statistically maintain croma values. With the effect of heat, the strength of the pigments could not be achieved. With the increase in the foaming agent ratio, the chroma values did not change at 5% and 10%. With the increase in *MD* power values, the lowest *ΔE* value was achieved when dried at 720 W 5–10% and 900 W 15% agents. When the product was exposed to less heat at high power values, the product retained its color values better. There is no statistically significant difference between the 5% and 10% values of the total color change carrier agent. When the proportion of foaming agents was increased to 15%, the color change decreased. The foaming rate has preserved the color pigments of the fruit.

3.5 Foam properties

The foam properties formed depending on the ratios of gypsophila extract are given in Table 3.

There is no statistically significant difference in the overrun values of the *Gypsophila extract* used in the study with the change in values. Overrun values range from 307.75 to 335.68 [43]. found overrun values in the range of 52.64–150.65 in the study of foaming agents pod protein and maltodextrin. Compared to the literature, it showed approximately twice the foaming properties of the *Gypsophila* extract used in the study. In the study, porosity values made a statistical difference. The increase in the foaming agent ratio increased the porosity value of the puree. This is because the space between the lamellae formed around the foam has expanded. The expansion value with the foaming agent used varied between 0.6224 and 0.6825. There was no statistically significant difference in the expansion value. When the values of other foam properties were examined, it was seen that the density value varied between 0.2142 and 0.2477. The drainage value varied between 68.19 and 78.08. The density and drainage values did not show any statistical difference according to the increase in the *Gypsophila* extract ratio.

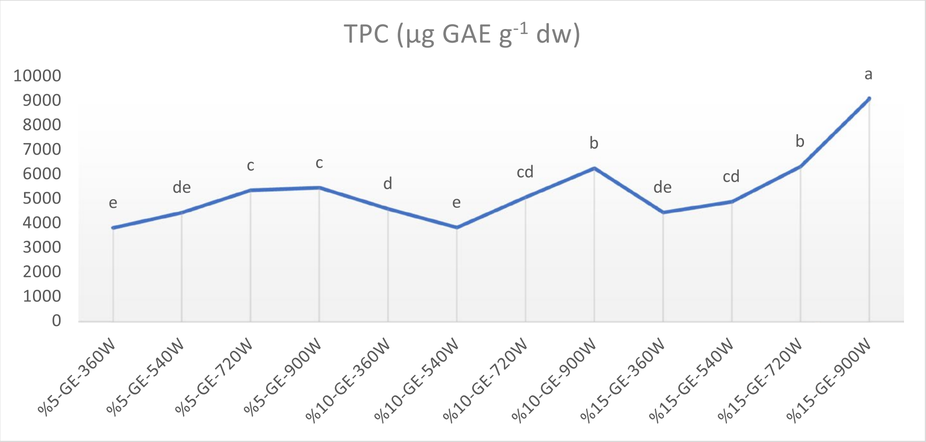

Fig. 3 Total phenolic substance content *TPC*

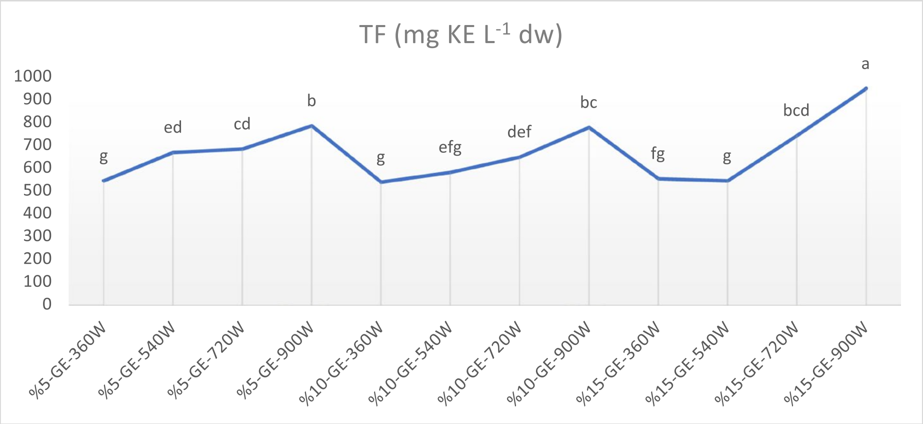

Fig. 4 Total flavonoid *TF* contents

3.6 Bioactive properties

MD power values and ratios of *Gypsophila* extract used as a foaming agent affected the bioactive content of tangerine flakes.

TPC Graph 1 shows the effects of different drying techniques on the total phenolic substance content of tangerine samples on *TPC*. The *TPC* values of the samples exhibited significant variability between 3822.2 and 9077.2 µg GAE g^{-1}. The highest TPC was achieved with the 15% −900 W microwave drying technique, followed by the 15% −720 W and 10–900 W techniques, respectively. The lowest *TPC* values were observed in 5% −360 W and 10% −540 W microwave drying techniques Fig. 3.

TF Graph 2 shows the effects of different drying techniques on the total flavonoid *TF* values of tangerine samples. The TF values of the samples showed a significant variability between 538.52 and 947.78 mg KE L^{-1}. The highest *TF* value was obtained with the 15% −900 W microwave drying technique, followed by 5% −900 W and 10–900 W techniques. The lowest *TF* values were determined in 5% −360 W, 10% −360 W, and 15% −540 W microwave drying techniques Fig. 4.

TAC Graph 3 reveals the effects of different drying techniques on the total antioxidant activity *TAC* values of tangerine samples. The *TAC* values of the samples showed a significant difference between 15.03 and 29.18 µmol TE g^{-1}. The highest *TAC* value was recorded with the 15% −900 W microwave drying technique, followed closely by the 10% −900 W technique. The lowest *TAC* values were observed in 10% −540 W and 15–540 W microwave drying techniques Fig. 5.

The amount of bioactive components in fruits and vegetables and the availability of these components in the body differ, which reveals the concepts of bioavailability and bioaccessibility. Food processing methods can significantly affect the bioaccessibility of these ingredients; It is suggested that it can make positive contributions to health by providing more bioactive compounds, especially by consuming small amounts of dried fruits and vegetables [44]. Drying studies conducted in previous years have revealed that proper microwave treatment can be an effective method to release and activate the bound phenolic compounds in tangerine pulp

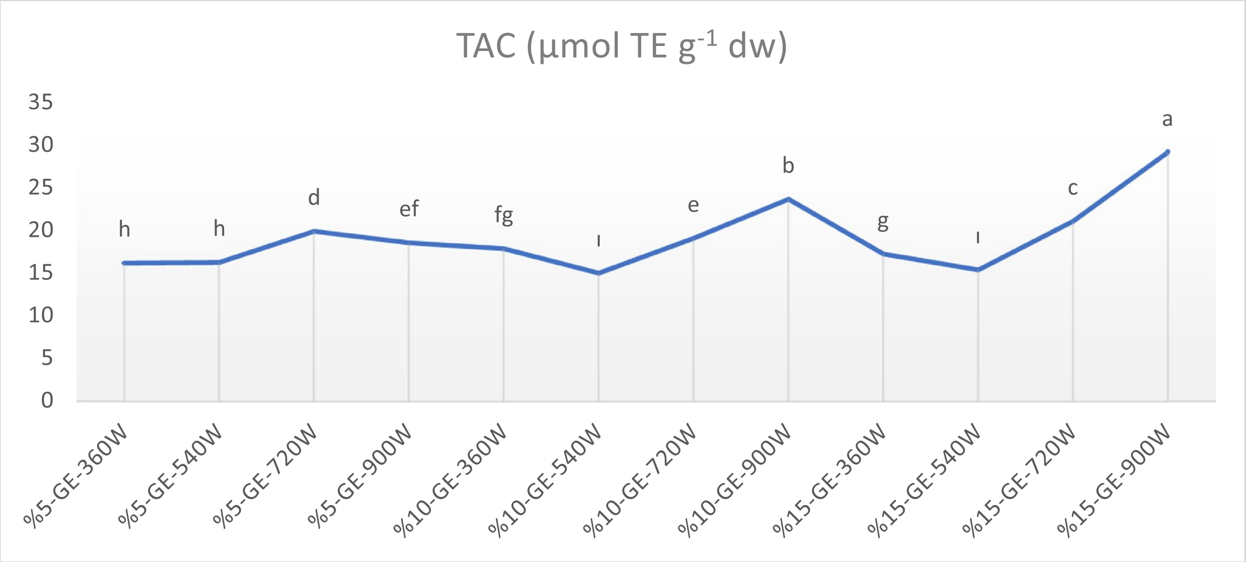

Fig. 5 Total antioxidant activity *TAC* contents

(Citrus mandarin pomace) and their skins and to increase their antioxidant activity [45]. The researchers also reported that the total flavonoid content (flavanol, flavanone, and flavonol compounds) increased with microwave power, but decreased with longer irradiation times. This is thought to be due to the degradation of some flavonoid compounds. In line with the literature, the study showed that the bioactive contents of dried mandarin samples increased with 900 W microwave processing power and these contents decreased with decreasing processing power to 360, 540, and 720 W. It is thought that this situation may be due to the degradation of bioactive compounds as a result of tangerine samples reaching the desired drying level later and being exposed to long irradiation times at low processing power. In addition, in our study, the effect of *Gypsophila* extract added to tangerine samples was found to be important and it was determined that bioactive compounds were better preserved at processing power with a high rate of *Gypsophila* extract contribution of 15% −900 W.

4 Conclusion

In this study, it is thought that the use of *Gypsophila* extract as a foaming agent will be suitable for use in other fruits and vegetables. Considering the cheap price of raw *Gypsophila* powder (100 g: 20 TL; 10/02/2025) and the amounts used in the studies, it is thought to be economical. It is thought to be suitable depending on the drying conditions preferred in other industrial studies. The stability value of the *Gypsophila* extract foam used in the study appears to be at a very good level. It is thought that this situation will reduce the drying time compared to the control samples (without foam) due to the heat-contact feature of the product dried as foam. The reduction in the drying times of the drying processes will cause the drying devices to consume less energy. This situation can contribute to the reduction of the drying time of especially very long industrial drying processes and allow the dry product to be served in a shorter time. In addition, the reduction of long industrial drying processes will also improve the economy by reducing energy consumption. It will reduce production costs and therefore increase profitability.

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Data availability No datasets were generated or analysed during the current study.

Declarations

Compliance with ethical standards This study has been prepared in accordance with ethical standards.

Competing interests The authors declare no competing interests.

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