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DRYING OF CHERRY LAUREL JUICE USING FOAM MAT DRYING TECHNIQUE AND INVESTIGATING THE EFFECT OF DRYING TEMPERATURE ON DRYING CHARACTERISTICS AND BIOACTIVE COMPONENTS

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ABSTRACT

This study aimed to optimize the foam properties for the foam mat drying (FMD) process and investigate the effect of drying temperatures (60, 70, and 80 °C) on the cherry laurel juice's drying characteristics and bioactive properties. Egg white protein (EWP), carboxymethyl cellulose (CMC), and mixing time (MT) variables were optimized using the Taguchi method to achieve the juice foam with maximum foam capacity and stability. The optimal conditions determined were 10% EWP, 0.3% CMC, and 12 min of MT. The drying times and effective moisture diffusivities (D_{eff}) for 60, 70, and 80 °C were recorded as 160, 120 and 90 min and 6.09×10^{-9}, 7.74×10^{-9} and 11.33×10^{-9} m^2/s, respectively. As the drying temperature increased, the total phenolic and total monomeric anthocyanin contents, and antioxidant activity values increased, but ascorbic acid content decreased. This research demonstrates that the FMD process can successfully be applied to dry juices with pronounced bioactive properties.
Keywords: Ascorbic acid, phenolic, foam capacity and stability, Taguchi optimization

KARAYEMİŞ ÖZÜTÜNÜN KÖPÜK MAT KURUTMA YÖNTEMİYLE KURUTULMASI VE KURUTMA SICAKLIĞININ KURUMA KARAKTERİSTİKLERİ VE BİYOAKTİF BİLEŞENLER ÜZERİNE ETKİSİNİN ARAŞTIRILMASI

ÖZ

Bu çalışmada, köpük mat kurutma (KMK) prosesi için köpük özelliklerinin optimize edilmesi ve farklı kurutma sıcaklıklarının (60, 70 ve 80 °C) ürünün kuruma karakteristikleri ve biyoaktif özelliklerine etkisinin araştırılması amaçlanmıştır. Optimum köpük kapasitesi ve stabilitesine sahip karayemiş

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özütü köpüğü elde etmek için yumurta akı proteini (EWP), karboksimetil selüloz (CMC) ve miksleme süresi (MS) değişkenleri Taguchi yöntemiyle optimize edilmiştir. Optimal koşullar %10 EWP, %0.3 CMC ve 12 dk. MS olarak belirlenmiştir. KMK işleminde 60, 70 ve 80 °C için kuruma süreleri ve efektif nem yayılımları sırasıyla 160, 120 ve 90 dk ve 6.09×10^{-9}, 7.74×10^{-9} ve 11.33×10^{-9} m^2/s olarak saptanmıştır. Bununla birlikte, kurutma sıcaklığının yükseltilmesiyle toplam fenolik madde ve toplam monomerik antosiyanin içerikleri ile antioksidan aktivite değerleri artmış askorbik asit içeriği ise azalmıştır. Bu çalışma, KMK işleminin belirgin biyoaktif özelliklere sahip meyve sularına başarıyla uygulanabileceğini göstermektedir.

Anahtar kelimeler: Askorbik asit, fenolik, köpük kapasitesi ve kararlılığı, Taguchi optimizasyon

INTRODUCTION

Cherry laurel (*Laurocerasus officinalis* L.) is the fruit of a tree belonging to the Rosaceae family, primarily consumed in the Eastern Black Sea region in Turkiye, where it grows naturally (Vahapoğlu et al., 2018). Also known as "Taflan", this fruit has a unique taste and its beneficial health properties are an important factor in its preference (Aktürk Gümüşay and Yıldırım Yalçın, 2019). In folk medicine, the fruits, leaves, and seeds of cherry laurel are utilized for their health-promoting properties. However, the bioactive compound content and the composition of cherry laurel fruits vary due to genetic, environmental factors, and post-harvest processing conditions (Kolaylı et al., 2003). For instance, the total anthocyanin, phenolic, carotenoid, and ascorbic acid contents, and DPPH radical scavenging activities of 11 different cherry laurel varieties collected from the Rize region varied between 123-205 mg C3G/100 g, 364-503 mg GAE/100 g, 207-278 mg/100 g, 3.7-6.8 mg/100 g and 21.2-32.2 μmol Trolox/g, respectively (Celik et al., 2011). Cherry laurel fruit, usually consumed as fresh fruit in June-July, is spoiled easily due to its high water content. Therefore, various preservation methods are employed to extend shelf life and enable consumption throughout the year (Beyhan, 2010). Cherry laurels can be processed into further processing products such as jam, marmalade, molasses, and fruit juice. This fruit, which is also processed into brine, is generally preserved by traditional drying methods (Beyhan, 2010; Liyana-Pathirana et al., 2006).

Drying, a common preservation method for foods with high water content (>75%), reduces storage, packaging, and transportation costs, ensuring microbiological and chemical stability (Bozkir, 2020). For this purpose, the hot air drying method is widely utilized. However, the waxy film layer formed on the upper surface of the dried material in this method causes prolonged drying time (Zielinska et al., 2018). As a consequence, as it leads to a reduction in bioactive components, alternative drying techniques are required (Bozkir et al., 2021). Altuntas et al. (2022) noted a drying time of 22.5 h at 50 °C in the hot air drying process for cherry laurel. In a study conducted by Güleç Özdemir (2017), the drying times for Taflan were determined as 20 min for microwave drying, 90 min for infrared drying, and 30 h for conventional (sun) drying. Turkmen et al. (2020) revealed that freeze drying was better than both hot air drying and ultrasound-assisted vacuum drying in terms of preserving the bioactive components found in cherry laurel fruit.

Foam mat drying (FMD) can also be preferred for products rich in bioactive ingredients due to its low investment cost and short drying time (Kanha et al., 2022). The basic principle of FMD involves converting fruit juice or puree into foam form by whipping with the help of foaming agents. The mixing process increases the surface area, facilitating effective drying by entrapping air within the product. Foaming agents play a crucial role in maintaining a stable foam throughout the drying process. The resulting foam is spread in a thin layer on a mat and then subjected to drying using methods such as hot air, freeze, and microwave drying. During the drying process, water vapors can easily escape to the external environment through the microchannels formed between the air cells, thus significantly reducing the drying time (Aslan and Ertaş, 2021; Azizpour et al., 2017; Osama et al., 2022).

Taguchi method is an optimization technique that provides robust design solutions by reducing the number of experiments. The most important advantage of this approach is that experimental studies are carried out at a lower cost, and practical solutions are produced in a shorter time compared to one factor at a time technique. In addition, process parameters that have insignificant effects on the process can be detected in this method (Güldane, 2023; Guldane and Dogan, 2022). Ana Maria et al. (2019) obtained instant cocoa powder enriched with lavender extract by FMD method. The researchers successfully optimized lavender extraction conditions using the Taguchi method. Similarly, using the Taguchi approach, Berktas et al. (2023) optimized the drying process of quince slices coated with $CaCI_2$ and pectin by hot air and microwave methods. In another study, the drying parameters for hot air drying for tomato slices were optimized by the Taguchi technique (Hussein et al., 2021). The purpose of this study was to optimize the foam mat drying process of cherry laurel juice using the Taguchi approach. In addition, the effect of drying temperature on the drying characteristics of the optimal foams and the bioactive properties of the powder products were also investigated.

MATERIALS AND METHODS

Materials

Cherry laurel fruits were harvested from the Sakarya University campus in the first week of August and stored at +4 °C. Foaming agents, such as egg white protein (EWP) and carboxymethyl cellulose (CMC) powders, were purchased from Tito (Turkiye). All chemicals and reagents utilized were of analytical purity and were obtained from Merck (Germany).

Methods

Preparation of cherry laurel juice

The fruits were washed after removing stems, branches, rotten fruits, and other non-fruit components by hand, and the fruit puree was then obtained using a solid fruit juicer. The puree and fruit pieces were transferred to a clean muslin cloth and pressed using a standard cheese press weighing 20 kg to extract the fruit juice. After the Brix value of the resulting cherry laurel juice was fixed at 10 °B, the juice was transferred into a brown glass bottle and stored at +4 °C.

Preparation of foaming agents

To prepare the stock EWP (20% w/v) and CMC (1% (w/v)) solutions, the powder samples were dissolved and hydrated completely by stirring with a magnetic stirrer at 200 rpm. The protein solution was stirred for 2 hours and stored at +4 °C, while the foam stabilizer solution was stirred continuously overnight at room conditions.

Cherry laurel foam production

100 g of fruit juice and the required amount of EWP (5, 10, 15%) and CMC (0.1, 0.3, 0.5%) were added to a beaker and mixed in a magnetic stirrer at 200 rpm for 15 min. Then, the foaming solution was transferred to the mixer bowl (Kenwood KM070, UK) and whipped at 160 rpm for different times (4, 8, and 12 min). Foam capacity and foam stability analyses were performed on the foam sample produced. Cherry laurel foam production was carried out according to the Taguchi L_9 experimental design presented in Table 2. The foam sample made under optimum conditions was used in the FMD of cherry laurel juices.

Foam mat drying of cherry laurel foam

The 105 ± 0.01 g of cherry laurel juice produced under optimal conditions was transferred to a rectangular aluminum tray (130 mm × 60 mm × 5 mm). The foam surface was gently leveled with a plastic spatula. The laying thickness of the foam was measured as 0.80 ± 0.01 cm. The drying tray was then transferred to a hot-air dryer (Neodry Drier Machine, Turkey). The cherry laurel foam was dehydrated at different temperatures (60, 70, and 80 °C) and a constant air velocity of 2 m/s. The literature studies (Güldane, 2023a; Iasnaia Maria de Carvalho et al., 2017; Maria de Carvalho Tavares et al., 2019) and laboratory pre-trial results were taken into consideration to determine these parameters. Throughout drying, the trays were weighed every 10 min using an electronic balance (Radwag PS 4500, Poland). The drying process was maintained until the samples reached 5% (wet basis (w.b)) moisture level. Following drying, the pieces were removed from the dryer and homogenized by a blender. The samples were then stored in airtight packages at +4 °C.

Experimental design

The Taguchi optimization method optimized the quality characteristics of cherry laurel juice foam, such as foam capacity and foam stability. The study was designed using Minitab 19.0 software. The studies were conducted based on Taguchi L_9 experimental design consisting of three factors and three levels (Table 2). In the optimization of foam properties, EWP (5, 10, and 15 %), CMC (0.1, 0.3, and 0.5 %), and MT (4, 8, and 12 min) variables were considered as control parameters (Table 1). Literature reviews (Asokapandian et al., 2016; Gao et al., 2022; Nemati et al., 2022; Salahi et al., 2015; Santos and Martins, 2022; Varhan et al., 2019) and laboratory preliminary trial reports were utilized to determine the process variables and their levels.

Table 1. Process variables and levels for cherry laurel foam production

Variables	Unit	Symbol	Level 1	Level 2	Level 3
Egg white protein (EWP)	%	A	5	10	15
Carboxymethyl cellulose (CMC)	%	B	0.1	0.3	0.5
Mixing time (MT)	min	C	4	8	12

Table 2. Taguchi L_9 (3^3) orthogonal design, experimental results, and S/N ratio values

Run	Variables			Responses			
	A	B	C	Foam capacity (%)	S/N ratio (dB)	Foam stability (min)	S/N ratio (dB)
1	5	0.1	4	52.00 ± 1.63	34.32	75.67 ± 0.47	37.58
2	10	0.1	8	67.00 ± 1.41	36.52	92.33 ± 1.70	38.31
3	15	0.1	12	63.33 ± 0.94	36.03	85.67 ± 2.05	38.66
4	5	0.3	8	100.33 ± 1.25	40.03	123.33 ± 0.47	42.09
5	10	0.3	12	108.00 ± 1.63	40.67	137.00 ± 2.49	42.73
6	15	0.3	4	83.33 ± 0.47	38.42	103.00 ± 2.16	40.26
7	5	0.5	12	102.33 ± 2.05	40.20	124.67 ± 1.41	41.98
8	10	0.5	4	87.00 ± 2.16	38.79	103.33 ± 0.47	40.28
9	15	0.5	8	88.33 ± 0.47	38.92	105.33 ± 0.47	40.45

The Taguchi technique is an optimization method capable of providing robust design solutions with few experiments. In this method, the response variables "larger is better", nominal is better," and "smaller is better" are optimized according to the Signal (S)/Noise (N) data. In this study, the "larger is better" option (Equation 1), which corresponds to the maximum levels of S/N ratios for each of the responses, was preferred since it is aimed to maximize the foam capacity and foam stability responses (Güldane, 2023).

$$S/_{N} = -10log\left[\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_{ij}^{2}}\right] \qquad (1)$$

Where y_{ij} is the i. result of the j. factor experiment and n is the number of replicate tests of i.

Analyzes

Foam properties of cherry laurel foam

Foam capacity (FC)

Foam capacity, which represents foamability, was determined by Equation 2 according to Guldane and Dogan (2022).

$$\text{FC}\ (\%) = \frac{M_L - M_F}{M_F} X100 \qquad (2)$$

where M_L ve M_F indicates the weight of pre-foam solution and foam, respectively.

Foam stability (FS)

In this study, the FS of the samples was evaluated using the drainage half-life values. The analysis was carried out using a method proposed by

Güldane (2023). Briefly, 40 g of cherry laurel foam was transferred into a plastic container (280 cm^3), which contained a hole about 6 mm in diameter at the bottom surface. The container was positioned on a level surface at a 45° C angle. The reduction in foam mass was measured every 5 min, and the time required to remove 20 g of liquid from the foam structure was calculated as the drainage half-life.

Determination of drying characteristics

Drying rate (DR)

The samples ' drying rate (DR) was calculated by Equation 3 using the method proposed by Bozkir et al. (2021).

$$DR = \frac{M_{t+dt} - M_t}{dt} \quad (3)$$

where M_{t+dt} is the moisture content at t+dt, and t represents the time.

Moisture ratio (MR)

The moisture content of cherry laurel juice foams was determined by Equation 4 (Dehghannya et al., 2019).

$$MR = \frac{M_t - M_e}{M_i - M_e}. \quad (4)$$

where M_t is the moisture content at any time (t). M_i and M_e are initial and equilibrium moisture contents, respectively.

Effective moisture diffusivity (D_{eff})

Effective moisture diffusivity (D_{eff}) values for drying cherry laurel juice foams were determined by calculating the D_{eff} value employing Equation 5 in accordance with Fick's second law (Watharkar et al., 2021).

$$\ln(\mathrm{MR}) = \ln(\frac{8}{\pi^2}) - (\pi^2 \frac{D_{eff}}{4L^2} t) \quad (5)$$

where L and t indicate the foam thickness and drying time, respectively.

Determination of bioactive properties

Extraction of bioactive components

The method proposed by Michalska-Ciechanowska et al. (2020) was partially modified and employed for extracting bioactive compounds from powdered samples. Briefly, 25 mL of methanol (80% (v/v)) was added to 1 g of cherry laurel extract foam powder, which was then mixed using a magnetic stirrer at 200 rpm for 15 min. Following this, the samples were filtered with filter paper and centrifuged at 5000 rpm for 10 min with a centrifuge (K242R, Centurion Scientific, UK). The resulting supernatant was stored in a brown glass bottle at +4 °C until further analysis.

Total phenolic matter (TPM) content

The total phenolic content of the samples was determined by the Folin-Ciocalteu (FC) colorimetric method proposed by Aktürk Gümüşay and Yıldırım Yalçın (2019). For this purpose, 200 µL FC reagent and 2 mL distilled water were added to 100 µL extract in a test tube. The tube was incubated for 3 min at room conditions, then 1 mL of 20 (%) Na_2CO_3 was added, vortexed, and kept in the dark for 1 hour. Subsequently, the absorbance of the samples was measured at 765 nm using a UV-VIS spectrophotometer (Shimadzu UV-1240, Japan). The TFM content of the samples was calculated in mg gallic acid equivalent (GAE) per 100 g of sample dry matter (dm) using a calibration curve plotted against standard gallic acid solutions.

Total monomeric anthocyanin (TMA) content

The TMA content of cherry laurel foam powder samples was determined using the pH differential method (Celik et al., 2011). To carry out this analysis, the sample extracts were diluted with both potassium chloride (pH=1) and sodium acetate (pH=4.5) buffer solutions. Following the dilution, the absorbance of the samples was measured at 515 and 700 nm after incubating for 15 min at room temperature. The final absorbance (*Abs*) for each sample was calculated using Equation 6.

$$Abs = (A_{510\,nm} - A_{700\,nm})_{pH\ 1.0} - (A_{510\,nm} - A_{700\,nm})_{pH\ 4.5} \quad (6)$$

TMA contents of cherry laurel powder samples were calculated according to Equation 7.

$$TMA\left(\frac{mg}{kg}\right) = \frac{Abs * M_W * DF * 1000}{\varepsilon * l} \quad (7)$$

where Mw is the molecular weight (445.2), DF is the dilution factor value, and ε is the molar absorbtivity constant (26,900) for cyanidin-3-glucoside (C3G).

Antioxidant activity assay

The antioxidant activities of the sample extracts were determined by calculating DPPH (1.1-diphenyl-2-picrylhydrazyl) radical scavenging activity (Equation 8) according to the methodology proposed by Aktürk Gümüşay and Yıldırım Yalçın (2019). This method involved mixing 3 mL of DPPH methanolic solution (0.1 mM) with 200 µL of the sample. The absorbance of the sample was then measured at 517 nm after waiting for 30 min in a dark environment.

$$DPPH(\%) = \left(\frac{Abs_{control} - A_{sample}}{A_{control}}\right) * 100 \qquad (8)$$

$A_{control}$ and A_{sample} represent the absorbance value for the DPPH solution and sample extract, respectively.

Ascorbic acid content

The ascorbic acid content of the cherry laurel extract powders was determined using a modified method proposed by Hışıl (2004). For this purpose, 9 mL oxalic acid solution (4% (w/v)) was added to 1 g of the sample and mixed at 200 rpm using a magnetic stirrer for 15 min. The mixture was then filtered through Whatman no:1 filter paper and stored in a brown glass bottle at +4 °C. For analysis, 9 mL of dye solution (2,6-dichlorophenolindophenol) was added to 1 mL of the sample in a test tube and vortexed. For the control sample, 1 mL of sample and 9 mL of distilled water were transferred to another test tube and mixed. The absorbance of the sample was measured at 518 nm using a UV-VIS spectrophotometer and adjusted to zero with the control sample. The vitamin C content of the sample was determined using a calibration curve generated from standard ascorbic acid solutions at different concentrations.

Statistical analysis

Analysis of variance (ANOVA) was performed using Minitab (Version 19.0, Minitab Inc., State College, PA, USA) software to determine the effects of production variables on the optimization of cherry laurel extract foam. Moreover, the differences in the analyzed results of the samples dried at different temperatures (60, 70, and 80 °C) were evaluated utilizing Duncan's comparison test with a 95% confidence interval.

RESULTS AND DISCUSSIONS

Taguchi optimization of cherry laurel foams

The FC and FS results of cherry laurel juice foams according to the Taguchi L_9 experimental design matrix and the average S/N ratios corresponding to each result are summarized in Table 2. The results indicate that the FC and FS values of the foam samples exhibited an improvement of approximately 108% and 81%, respectively, compared to the initial process parameters ($A_1B_1C_1$). In addition, the mean values of S/N ratios for FC and FS in cherry laurel foam production ranged between 34.42-40.67 dB and 37.58-42.73 dB, respectively. The effect of the process variables (EWP (%), CMC (%), and MT (min)) on the observed results is depicted in the S/N ratio average response graph, presented in Figure 1 a-b. It can be seen from the figures that the process variables have a similar impact on both FC and FS values. Since the main objective of the study was to maximize the FC and FS values, the highest S/N ratio average value for each process variable in the response graphs was utilized to determine the optimum production conditions. Based on the experimental results, a sample with optimum foam properties could be produced by whipping cherry laurel juice containing 10% EWP and 0.3% CMC at room temperature for 12 min ($A_2B_2C_3$).

In the production of cherry laurel juice foam, an increase in the EWP concentration from 5% to 10% significantly affected foam properties. However, higher protein concentrations (15%) did not lead to a substantial improvement in both FC and FS responses. Similar observations could be made regarding the CMC variable as a foam stabilizer. On the other hand, an increase in mixing time had a positive contribution to foam properties. Furthermore, the model ANOVA data, with a high coefficient of determination ($R^2 > 0.99$), indicated that the influence of the process parameters on both responses was statistically significant ($P < 0.05$). EWP showed the most significant effect on cherry laurel foam production, with a higher contribution rate (80.13% for FC and 68.09% for FS), followed by MT (15.36% for FC and 22.90% for FS) and CMC (4.42% for FC and 8.68% for FS) (Table 3).

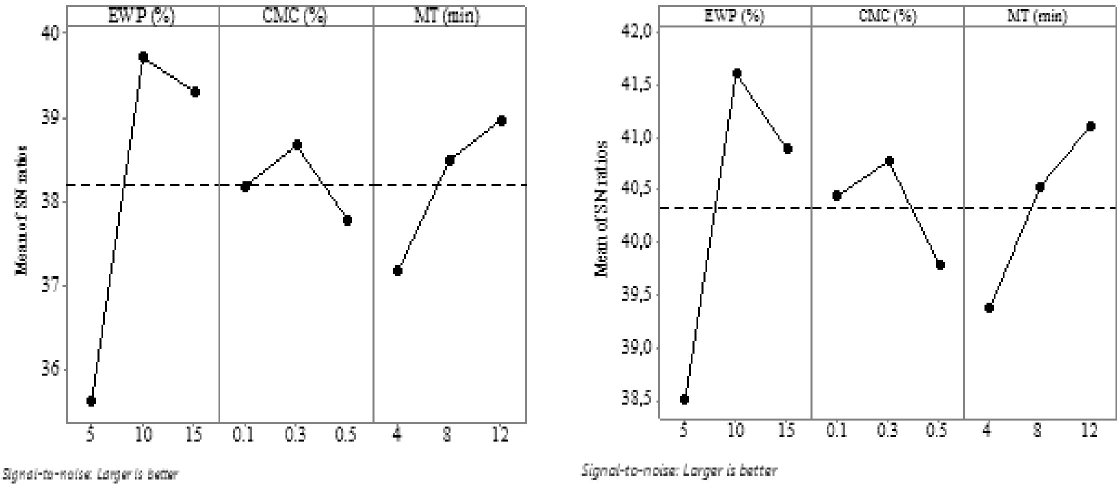

Figure 1. S/N response graphs for foam capacity (a) and foam stability (b)

Table 3. ANOVA results for foam capacity and foam stability responses

		Foam capacity (FC)				Foam stability (FS)			
Source	DF	Sum of squares	F-Value	*p*-Value	Contribution ratio (%)	Sum of squares	F-Value	*p*-Value	Contribution ratio (%)
A	2	2359.80	752.54	0.001*	80.13	2141.51	203.12	0.005*	68.09
B	2	129.95	41.44	0.024*	4.41	272.91	25.89	0.037*	8.68
C	2	452.25	144.22	0.007*	15.36	720.32	68.32	0.014*	22.90
Error	2	3.14			0.10	10.54			0.33
Total	8	2945.14				3145.28			
R^2		99.89				99.66			

* significant ($P < 0.05$).

In the literature, there are conflicting results on the effect of process variables on foam properties in models designed for FMD. For instance, Watharkar et al. (2021) reported that an increase in skim milk powder concentration in the production of ripe banana puree foam resulted in a decrease in foam density without influencing FS. Similarly, Macedo et al. (2021) reported that the concentration of foaming agent (Emustab) and mixing time did not significantly affect FS but improved the foaming property in FMD of white and red dragon fruit. On the other hand, Thuy et al. (2022) observed a significant improvement ($P < 0.05$) in both FC and FS responses with an increase in albumin content and mixing time during the production of Magenta leaf extract foam. Salahi et al. (2015) noted that an increase in EWP concentration from 1% to 3% and an increase in MT from 120 s to 10 min led to reduced foam density and liquid drainage from the foam structure.

Overall, these varying observations highlight that the impact of process variables and their levels on foam properties in FMD models is product-specific and might yield different observations depending on the particular characteristics of the material being processed.

Drying characteristics

Drying time, drying rate (DR), moisture content (MC), and effective moisture diffusivity (D_{eff}) were determined from the FMD process of cherry laurel juice foam produced under optimum conditions. The moisture variation of the fruit juice foam during drying is given in Figure 2a. The figure shows that the drying time of foam samples decreased with the increasing temperature, as expected. In the drying study, the drying times of the samples dried at 60, 70, and 80 °C were 160, 120, and 90 min, respectively (Figure 2a). The drying time decreased by 43.75% when the temperature increased from 60 to 80 °C. This situation can be attributed to the decrease in the internal resistance of water diffusion in the product due to the increased drying temperature (Macedo et al., 2021; Salahi et al., 2015). In addition, the decrease in the relative humidity of the drying air with increasing temperature is also a practical factor contributing to the reduction in drying time (Kılıç and Tabanlıgil Calam, 2020). Turkmen et al. (2020) reported the drying time of cherry laurels decreased by about 63.11% when the drying temperature increased from 60 to 70 °C. These results indicate that the FMD process significantly increases the moisture diffusion rate depending on the product characteristics.

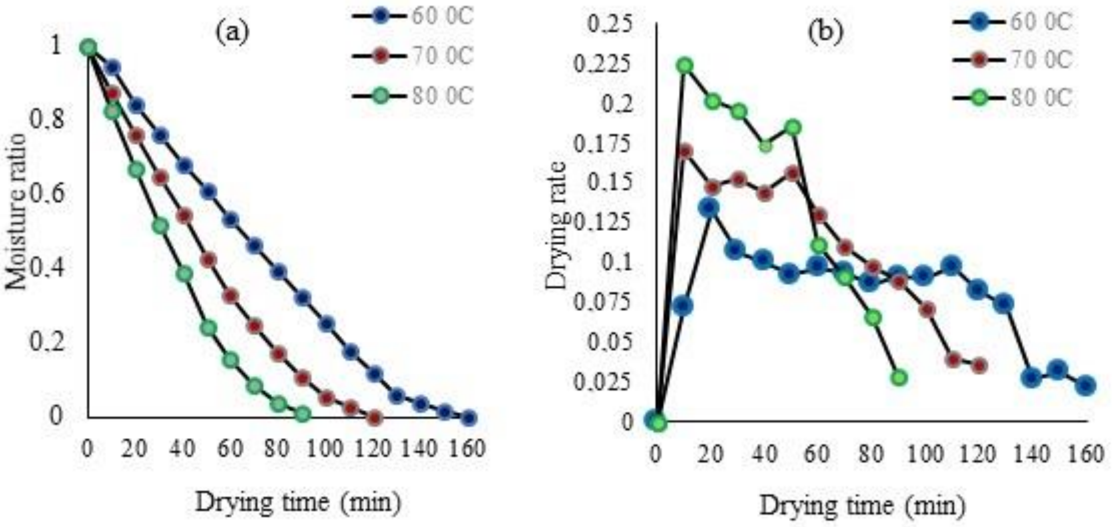

Figure 2. The effect of drying temperature on moisture ratio (a) and drying rate (b)

The variation in DR based on temperature for cherry laurel juice foam dried at different temperatures is shown in Figure 2b. When the figure is analyzed, it can be seen that the drying rate for cherry laurel foam is notably high in the initial stage of the drying process. This situation can be attributed to the easy evaporation of water from surfaces with higher moisture content. However, in the later stages of drying, the drying rate decreases, primarily attributed to internal resistance in removing moisture from the inner regions (Salahi et al., 2015).

The D_{eff} of cherry laurel foam in the FMD process was calculated using Equation 5, and the values at 60, 70, and 80 °C were determined as 6.09×10^{-9}, 7.74×10^{-9} and 11.33×10-9 m^2/s, respectively. D_{eff}, which defines mass transfer properties within foods concerning observed internal moisture mobility, generally vary between 10^{-12} m^2/s and 10^{-8} m^2/s (Whatarkar et al. 2021). In addition, it has been reported that the D_{eff} value changed between 10^{-8} m^2/s and 10^{-10} in various foam mat-dried products, and the temperature variable was identified as the most crucial factor influencing moisture transfer in FMD (Dehghannya et al., 2019; Khodifad and Kumar, 2020; Salahi et al., 2015; Thuy et al., 2022). The results of the present study were found to be consistent with the literature data.

Bioactive properties

The TFM, TMA, ascorbic acit contents, and DPPH (%) radical scavenging activity results of both the control sample and cherry laurel juice foam powders, dried at different temperatures (60, 70, and 80 °C), are presented in Table 4. The results demonstrated statistically significant differences in the bioactive contents of the cherry laurel juice containing foaming agents and the samples subjected to the drying process (P <0.05). Furthermore, it was observed that the TFM and TMA contents as well as DPPH (%) values of the samples increased, and ascorbic acid content decreased due to the increase in drying temperature in the FMD process.

Polyphenols are secondary metabolites in plants and possess various biological effects, including antioxidant, antibacterial, and anticancer properties. In our study, the TFM contents of cherry laurel powders ranged between 124.46 ± 4.46 and 299.24 ± 0.37 mg GAE/100 g. The values obtained were lower than the TFM content of the control sample (444.43 ± 0.18). The previous research conducted by Gümüşay and Yalçın (2019) determined the TFM content of cherry laurel fruit dried by freeze drying as 1552.74 ± 44.02 mg GAE/ 100 g, considerably higher than our results. This condition may be related to product variations (Beyhan, 2010) and the incorporation of maltodextrin and foaming agents into the formulation, which may dilute and reduce the phenolic content, leading to lower TFM (Fauziyah et al., 2022). However, Celik et al. (2011) reported different cherry laurel genotypes with TFM contents between 364-503 mg GAE/100 g on a wet weight basis. In the FMD process, the TFM content of the samples tended to increase as the drying temperature increased. This phenomenon could be attributed to the reduction in drying time due to elevated drying temperature, thereby limiting the degradation of phenolic compounds by minimizing the time the product is placed in the dryer (Brar et al., 2020). In our study, the TFM content improved by approximately 140% due to increasing the temperature from 60 °C to 80 °C. Similarly, Turkmen et al. (2020) reported an 86% increase in TFM content due to increasing the drying temperature from 60 to 70 °C in hot air drying of cherry laurel fruit. Also, a similar enrichment in phenolic substances was observed in the FMD of peaches due to increased drying temperatures (Brar et al., 2020).

Anthocyanins are natural pigments responsible for the diverse colors in plants ranging from red to blue. It was found that cherry laurel juice was enriched with monomeric anthocyanins due to drying with the FMD process, especially with increasing temperatures. The TMA content in cherry laurel powders showed a substantial decrease (~54%) when the drying temperature was decreased from 80 to 60 °C (Table 4). This result may be attributed to the prolonged exposure of anthocyanin compounds to oxygen during relatively low-temperature drying and their subsequent degradation facilitated by polyphenol oxidase enzymes. In a similar study, the TMA contents decreased from 76.22 ± 2.67 to 39.93 ± 2.17 in mg C3G/ 100 g dm as a result of reducing the drying temperature from 70 to 50 °C during the hot air drying of cherry laurel fruit (Turkmen et al., 2020). These comparable results could be attributed to the diluting effects of the foaming agents (EWP, CMC, and MT) used in the FMD process. In addition, it was reported that the anthocyanin content of cranberry dried in a convective dryer at 70 °C was higher than 50 °C (Tontul et al., 2018). Similar trends were observed by Kanha et al. (2022) in FMD of black rice bran extract. These studies emphasize the importance of considering the degradation of complex anthocyanins into their monomeric forms, especially under high-temperature drying conditions.

Oxygen, an essential element for human life, triggers oxidative stress by causing the formation of reactive oxygen species within cells. Antioxidant substances serve as a defense mechanism against the effects of this stress, making the consumption of antioxidant-rich food products crucial for maintaining health (Aktürk Gümüşay and Yıldırım Yalçın, 2019). The DPPH radical scavenging assay is widely used to evaluate the ability of antioxidants to scavenge free radicals. The binding potential of antioxidants with free radicals determines the scavenging activity of a sample (Liyana-Pathirana et al., 2006). The DPPH (%) values of foam mat dried cherry laurel powders ranged between 27.09 ± 0.14% and 53.81 ± 0.17%. Although the antioxidant activity of the powder samples was lower than the control (78.50 ± 0.11%), the antioxidant activity of the samples increased significantly (*P* <0.05) due to the increase in drying temperature in the production of cherry laurel juice powder.

The vitamin C content in cherry laurel powders, obtained through the FMD method, varied between 1.0 ± 0.07 and 3.72 ± 0.02 in mg C3G/100 g sample dm. It was observed that the ascorbic acid content in these samples decreased significantly (*P* <0.05) with increasing drying temperature. This decline may be attributed to the higher degradation of ascorbic acid at higher temperatures. Comparable results were noted in the FMD of papaya pulp (Abd El-Salam et al., 2021) and tomato (Kadam et al., 2012).

Table 4. Bioactive properties of foam mat dried cherry laurel foam powders

Property	Drying temperature (°C)			
	Control*	60	70	80
TFM (mg GAE/100 g dm)	444.43 ± 0.18^{a}	124.46 ± 4.46^{d}	237.41 ± 3.57^{c}	299.24 ± 0.37^{b}
TMA (mg C3G/100 g dm)	128.75 ± 1.02^{a}	45.59 ± 0.17^{d}	87.81 ± 0.46^{c}	98.90 ± 0.88^{b}
DPPH (%)	78.50 ± 0.11^{a}	27.09 ± 0.14^{d}	50.67 ± 0.27^{c}	53.81 ± 0.17^{b}
Ascorbic acid (mg/100 g dm)	4.38 ± 0.13^{a}	3.72 ± 0.02^{b}	1.97 ± 0.00^{c}	1.0 ± 0.07^{d}

Results are given as mean ± standard deviation. Different letters in the same row indicate significant differences (*P* <0.05). *Control sample refers to the optimal pre-foam solution.

CONCLUSION

In this study, cherry laurel juice, which has prominent bioactive properties, was dried using the foam mat drying method. The optimal foam, obtained by whipping cherry laurel juice containing 10% egg white protein and 0.3% carboxymethyl cellulose for 12 min, was spread in an aluminum tray and dried at 60, 70, and 80 °C at an air velocity of 2 m/s. The effect of drying temperature on drying characteristics and bioactive components was investigated. The results revealed an improvement in drying factors such as drying rate and effective moisture diffusion with increasing temperature during the foam mat drying process. In addition, it was observed that the total phenolic content, total monomeric anthocyanin, and DPPH (%) radical scavenging activity values increased by approximately 140%, 117%, and 99%, respectively. On the other hand, the vitamin C content decreased by about 73% when the drying temperature increased from 60 to 80 °C. The results demonstrated that the foam mat drying technique can be successfully applied in producing fruit powders with high bioactive content.

CONFLICT OF INTEREST

The author(s) declares no conflict of interest.

AUTHORS' CONTRIBUTIONS

Mehmet Güldane: Literature review, Methodology, Data Curation, Analysis, Writing-original draft. Hamza Bozkır: Methodolgy Review and Editing. All authors approved the final manuscript and accepted to be held responsible for the content.

REFERENCES

Abd El-Salam, E. A. E. S., Ali, A. M., Hammad, K. S. (2021). Foaming process optimization, drying kinetics and quality of foam mat dried papaya pulp. *Journal of Food Science and Technology*, *58*(4), 1449–1461. https://doi.org/10.1007/s13197-020-04657-2

Aktürk Gümüşay, Ö., Yıldırım Yalçın, M. (2019). Effects of Freeze-Drying Process on Antioxidant and Some Physical Properties of Cherry Laurel and Kiwi Fruits. *Akademik Gıda*, *17*(1), 9–15. https://doi.org/10.24323/akademik-gida.543985

Altuntaş, E., Taşova, M., Polatcı, H., Saraçoğlu, O. (2022). Effects of Genotypes and Drying Temperatures on Color and Thin Layer Drying

Models of Cherry Laurel (Laurocerasus Officinalis L.) Fruits. *Kastamonu Üniversitesi Orman Fakültesi Dergisi*, *22*(1), 24–32. https://doi.org/10.17475/kastorman.1095719

Ana Maria, B., Tamara, J., Ana Jurinjak, T., Davor, V., Jasenka Gajdoš, K., Maja, B. (2019). Applicability of Foam Mat Drying Process for Production of Instant Cocoa Powder Enriched with Lavender Extract. *Food Technology and Biotechnology*, *57*(2), 159–170. https://doi.org/10.1007/978-3-030-82688-8_1

Aslan, M., Ertaş, N. (2021). Foam drying of aquafaba: Optimization with mixture design. *Journal of Food Processing and Preservation*, *45*(3), 1–11. https://doi.org/10.1111/jfpp.15185

Asokapandian, S., Venkatachalam, S., Swamy, G. J., Kuppusamy, K. (2016). Optimization of Foaming Properties and Foam Mat Drying of Muskmelon Using Soy Protein. *Journal of Food Process Engineering*, *39*(6), 692–701. https://doi.org/10.1111/jfpe.12261

Azizpour, M., Mohebbi, M., Yolmeh, M., Abbasi, E., Sangatash, M. M. (2017). Effects of different hydrocolloids on foaming properties of shrimp puree: a cluster analysis. *Journal of Food Measurement and Characterization*, *11*(4), 1892–1898. https://doi.org/10.1007/s11694-017-9571-9

Berktas, S., Cam, M., Salum, P., Erbay, Z. (2023). Microwave drying of quince coated with seed gum and pectin: A Taguchi optimization, techno-functional properties, and aromatic compounds. *Journal of Food Science*, *May*, 2919–2932. https://doi.org/10.1111/1750-3841.16660

Beyhan, O. (2010). A Study on selection of promising native cherry laurel (Prunus Laurocerasus L.) Genotypes from Sakarya, Turkey. *Journal of Animal and Plant Sciences*, *20*(4), 231–233.

Bozkir, H. (2020). Effects of hot air, vacuum infrared, and vacuum microwave dryers on the drying kinetics and quality characteristics of orange slices. *Journal of Food Process Engineering*, *43*(10), 1–12. https://doi.org/10.1111/jfpe.13485

Bozkir, H., Tekgül, Y., Erten, E. S. (2021). Effects of tray drying, vacuum infrared drying, and vacuum microwave drying techniques on quality characteristics and aroma profile of orange peels. *Journal of Food Process Engineering*, *44*(1). https://doi.org/10.1111/jfpe.13611

Brar, A. S., Kaur, P., Kaur, G., Subramanian, J., Kumar, D., Singh, A. (2020). Optimization of Process Parameters for Foam-Mat Drying of Peaches. *International Journal of Fruit Science*, *20*(S3), S1495–S1518. https://doi.org/10.1080/15538362.2020.1812017

Celik, F., Ercisli, S., Yilmaz, S. O., Hegedus, A. (2011). Estimation of certain physical andchemical fruit characteristics ofvarious cherry laurel (Laurocerasusofficinalis roem.) genotypes. *HortScience*, *46*(6), 924–927. https://doi.org/10.21273/hortsci.46.6.924

Dehghannya, J., Pourahmad, M., Ghanbarzadeh, B., Ghaffari, H. (2019). Heat and mass transfer enhancement during foam-mat drying process of lime juice: Impact of convective hot air temperature. *International Journal of Thermal Sciences*, *135*(December 2017), 30–43. https://doi.org/10.1016/j.ijthermalsci.2018.07.023

Fauziyah, N., Ifie, I., Syarief, O., Darniadi, S. (2022). Impact of hydrocolloid and foaming agent on the physicochemical, microstructural and bioactive characteristics of foam-mat freeze-dried tapai (fermented black glutinous rice) powder. *Food Science and Nutrition*, *May*, 1–12. https://doi.org/10.1002/fsn3.3098

Gao, R., Xue, L., Zhang, Y., Liu, Y., Shen, L., Zheng, X. (2022). Production of blueberry pulp powder by microwave-assisted foam-mat drying: Effects of formulations of foaming agents on drying characteristics and physicochemical properties. *Lwt*, *154*, 112811. https://doi.org/10.1016/j.lwt.2021.112811

Güldane, M. (2023a). Optimizing foam mat drying process for cornelian cherry pulp using response surface methodology and artificial neural networks. *Revista Mexicana de Ingeniería Química*, *22*(3), 1–14. https://doi.org/10.24275/rmiq/Alim2386

Güldane, M. (2023b). *Optimizing foam quality characteristics of model food using Taguchi-based fuzzy logic method. Journal of Food Process Engineering*, *46*(8), e14384. https://doi.org/10.1111/jfpe.14384

Guldane, M., Dogan, M. (2022). Multi-response optimization of process parameters of saponin-based model foam using Taguchi method and gray relational analysis coupled with principal component analysis. *Journal of Food Processing and Preservation*, *46*(5), 1–14. https://doi.org/10.1111/jfpp.16553

Güleç, F., Özdemir, G. D. T. (2017). Investigation of drying characteristics of Cherry Laurel (Laurocerasus officinalis Roemer) fruits. *Akademik Ziraat Dergisi*, *6*(1), 73–80.

Hussein, J. B., Oke, M. O., Abiona, O. O., Adebayo, Q. (2021). Optimization of processing parameters for drying of tomatoes (Solanum lycopersicum L.var) slices using Taguchi technique. *Journal of Food Processing and Preservation*, *45*(2), 0–2. https://doi.org/10.1111/jfpp.15149

Iasnaia Maria de Carvalho, T., Nogueira, T. Y. K., Mauro, M. A., Gómez-Alonso, S., Gomes, E., Da-Silva, R., Hermosín-Gutiérrez, I., Lago-Vanzela, E. S. (2017). Dehydration of jambolan [Syzygium cumini (L.)] juice during foam mat drying: Quantitative and qualitative changes of the phenolic compounds. *Food Research International*, *102*(September), 32–42. https://doi.org/10.1016/j.foodres.2017.09.068

Kadam, D. M., Wilson, R. A., Kaur, S., Manisha. (2012). Influence of foam mat drying on quality of tomato powder. *International Journal of Food Properties*, *15*(1), 211–220. https://doi.org/10.1080/10942911003763701

Kanha, N., Regenstein, J. M., Laokuldilok, T. (2022). Optimization of process parameters for foam mat drying of black rice bran anthocyanin and comparison with spray- and freeze-dried powders. *Drying Technology*, *40*(3), 581–594. https://doi.org/10.1080/07373937.2020.1819824

Khodifad, B. C., Kumar, N. (2020). Foaming properties of custard apple pulp and mathematical modelling of foam mat drying. *Journal of Food Science and Technology*, *57*(2), 526–536. https://doi.org/10.1007/s13197-019-04082-0

Kılıç, F., Tabanlıgil Calam, T. (2020). Kırmızı Kapya Biberlerinin (Capsicum Annuum l.) Kurutma ve Rehidrasyon Kinetiklerinin Belirlenmesi, Kurutma İşleminin Termodinamik Analizi. *Deu Muhendislik Fakultesi Fen ve Muhendislik*, *22*(65), 343–352. https://doi.org/10.21205/deufmd.2020226503

Liyana-Pathirana, C. M., Shahidi, F., Alasalvar, C. (2006). Antioxidant activity of cherry laurel fruit (Laurocerasus officinalis Roem.) and its concentrated juice. *Food Chemistry*, *99*(1), 121–128. https://doi.org/10.1016/j.foodchem.2005.06.046

Macedo, L. L., Corrêa, J. L. G., Araújo, C. da S., Vimercati, W. C., Pio, L. A. S. (2021). Process optimization and ethanol use for obtaining white and red dragon fruit powder by foam mat drying. *Journal of Food Science*, *86*(2), 426–433. https://doi.org/10.1111/1750-3841.15585

Maria de Carvalho Tavares, I., Bonatto Machado de Castilhos, M., Aparecida Mauro, M., Mota Ramos, A., Teodoro de Souza, R., Gómez-Alonso, S., Gomes, E., Da-Silva, R., Hermosín-Gutiérrez, I., Silva Lago-Vanzela, E. (2019). BRS Violeta (BRS Rúbea × IAC 1398-21) grape juice powder produced by foam mat drying. Part I: Effect of drying temperature on phenolic compounds and antioxidant activity. *Food Chemistry*, *298*(June), 124971. https://doi.org/10.1016/j.foodchem.2019.124971

Michalska-Ciechanowska, A., Majerska, J., Brzezowska, J., Wojdyło, A., Figiel, A. (2020). The influence of maltodextrin and inulin on the physico-chemical properties of cranberry juice powders. *ChemEngineering*, *4*(1), 1–12. https://doi.org/10.3390/chemengineering4010012

Nemati, A., Motamedzadegan, A., Milani, J. M. (2022). Evaluating the effect of different foam mat drying methods on the properties of orange beverage powder. *Journal of Food Processing and Preservation*, *46*(6), 1–13. https://doi.org/10.1111/jfpp.16539

Osama, K., Younis, K., Qadri, O. S., Parveen, S., Siddiqui, M. H. (2022). Development of under-utilized kadam (Neolamarkia cadamba) powder using foam mat drying. *Lwt*, *154*, 112782. https://doi.org/10.1016/j.lwt.2021.112782

Salahi, M. R., Mohebbi, M., Taghizadeh, M. (2015). Foam-Mat Drying of Cantaloupe (Cucumis melo): Optimization of Foaming Parameters and Investigating Drying Characteristics. *Journal of Food Processing and Preservation*, *39*(6), 1798–1808. https://doi.org/10.1111/jfpp.12414

Santos, L. G., Martins, V. G. (2022). Recovery of phenolic compounds from purple onion peel using bio-based solvents: Thermal degradation kinetics and color stability of anthocyanins. *Journal of Food Processing and Preservation*, *46*(12), 1–9. https://doi.org/10.1111/jfpp.17161

Thuy, N. M., Tien, V. Q., Tai, N. Van, Minh, V. Q. (2022). Effect of Foaming Conditions on Foam Properties and Drying Behavior of Powder from Magenta (Peristrophe roxburghiana) Leaves Extracts. *Horticulturae*, *8*(6). https://doi.org/10.3390/horticulturae8060546

Tontul, I., Eroğlu, E., Topuz, A. (2018). Convective and refractance window drying of cornelian cherry pulp: Effect on physicochemical properties. *Journal of Food Process Engineering*, *41*(8), 1–8. https://doi.org/10.1111/jfpe.12917

Turkmen, F., Karasu, S., Karadağ, A. (2020). Effects of Different Drying Methods and Temperature on the Drying Behavior and Quality Attributes of Cherry Laurel Fruit. *Processes*, *2*, 1–15.

Vahapoğlu, B., Altan, E. N., Gülseren, İ. (2018). Karayemiş meyvesi̇ni̇n Bi̇yoakti̇f Özellikleri ve Fonksi̇yonel Gıdalarda Kullanim Potansi̇yeli̇. *Gıda*, *43*(5), 751–764. https://doi.org/10.15237/gida.gd18055

Varhan, E., Elmas, F., Koç, M. (2019). Foam mat drying of fig fruit: Optimization of foam composition and physicochemical properties of fig powder. *Journal of Food Process Engineering*, *42*(4), 1–13. https://doi.org/10.1111/jfpe.13022

Watharkar, R. B., Chakraborty, S., Srivastav, P. P., Srivastava, B. (2021). Foaming and foam mat drying characteristics of ripe banana [Musa balbisiana (BB)] pulp. *Journal of Food Process Engineering*, *44*(8). https://doi.org/10.1111/jfpe.13726

Zielinska, M., Ropelewska, E., Zapotoczny, P. (2018). Effects of freezing and hot air drying on the physical, morphological and thermal properties of cranberries (Vaccinium macrocarpon). *Food and Bioproducts Processing*, *110*, 40–49. https://doi.org/10.1016/j.fbp.2018.04.006