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EVALUATION OF FOAM-MAT DRYING BEHAVIOUR OF CRAB APPLE (*MALUS FLORIBUNDA*) FRUIT JUICE AND POWDER QUALITY

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ABSTRACT
Malus floribunda (MF) is an ornamental plant and the fruits with its red flesh have potential to be used as natural food colorant. In this study, the effects of faba bean protein concentrate (FB) and maltodextrin (MD) levels on MF juice foam stability was evaluated. In addition, the effects of drying conditions (temperature/power) on drying kinetics and powder quality (powder flow properties, colour, and anthocyanin content) were determined. The foam stability was significantly dependent on the FB level (P <0.05), but MD addition didn't have any significant effect (P >0.05). Drying period was reduced with foam-mat drying compared to control, and the average Carr index values were found between 17.3-26.0%, while the Hausner ratios were between 1.21-1.35. The redness and lightness values of foam-mat dried powders were comparably higher than the control and MD-added sample at every drying condition (P <0.05), although the anthocyanin content decreased with increasing drying temperatures.
Keywords: *Malus floribunda*, foam, faba bean protein, powder properties

SÜS ELMASI (*MALUS FLORIBUNDA*) SUYUNUN KÖPÜK KURUMA DAVRANIŞI VE TOZ ÜRÜNÜN KALİTE ÖZELLİKLERİNİN BELİRLENMESİ

ÖZ
Malus floribunda (MF) bir peyzaj bitkisidir, ancak kırmızı meyve eti rengi ile doğal renk maddesi olarak kullanım potansiyeli bulunmaktadır. Bu çalışmada, bakla proteini konsantresi (FB) ve maltodekstrin (MD) miktarının köpük kararlılığı üzerine etkileri incelenmiştir. Ayrıca kurutma koşullarının (sıcaklık/güç), kuruma kinetiği ve toz ürün özellikleri (toz akış özelliği, renk ve antosiyanin miktarı) üzerine etkileri belirlenmiştir. Köpük kararlılığının FB miktarından önemli düzeyde etkilendiği (P <0.05), ancak MD ilavesinin köpük kararlılığını arttırma üzerine önemli düzeyde bir etkisi olmadığı belirlenmiştir (P >0.05). Kuruma süresinin köpük haline getirilen örneklerde kısaldığı, bunun yanı sıra ortalama Carr endeksi değerlerinin %17.3-26.0 ve Hausner oranının 1.21-1.35 arasında olduğu tespit edilmiştir. Köpük kurutma yöntemiyle kurutulan toz ürünün, tüm kurutma koşullarında kırmızılık ve parlaklık değerleri, kontrol ve MD ilaveli örneklerden daha yüksektir (P <0.05), ancak antosiyanin içeriğinin kuruma sıcaklığı artışına bağlı olarak azaldığı görülmüştür.
Anahtar kelimeler: *Malus floribunda*, köpük, bakla proteini, toz ürün özellikleri

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INTRODUCTION

Malus floribunda is an ornamental plant classified in Rosacea family, and the plant is originated from Japan, therefore it is also called as Japanese crab apple tree (Cepeda and Villaran, 1999; Kırbağ and Aydoğan, 2017). Although the plant is cultivated in landscapes for its beautiful pink-reddish flowers, the apples with sour and astringent taste are used for production of vinegar and marmalade in Turkey as a remedy against diabetes (Kırbağ and Aydoğan, 2017; Coklar et al., 2018). Red flesh of this apple reflects richness of anthocyanin pigments; however the literature is limited only about the phytochemical and antimicrobial properties of apple and the rheological properties of concentrated apple juice rather than utilizing the fruit as a food ingredient (Cepeda et al., 1999; Kırbağ and Aydoğan, 2017; Coklar et al., 2018).

The foam-mat drying has two stages; first the material is foamed and second the stable foam is dried. Drying of stable foam structure improves the moisture transfer by increasing the interfacial area due to air incorporation with foaming (Kudra and Ratti, 2006; Hardy and Jideani, 2017), while the nutrients are preserved by low temperature and short drying time of foam-mat drying (Zheng et al., 2011; Chaux-Gutiérrez et al., 2017; Ng and Sulaiman, 2018). Also the powder properties such as flowability, cohesiveness, rehydration and hygroscopicity are improved by foam-mat drying method (Seerangurayar et al., 2017; Ng and Sulaiman, 2018). Several foaming materials are employed including egg albumin, ovalbumin, whey protein isolate, gelatin, soy protein isolate, commercial foam stabilizers (glycerine monostearate, gum Arabic, methyl cellulose, Na-carboxymethyl cellulose, sorbitan monostearate, etc.), and other drying agents (maltodextrin) (Zheng et al., 2011; Franco et al., 2016; Chaux-Gutiérrez et al., 2017; Seerangurayar et al., 2017; Dehghannya et al., 2018; Ng and Sulaiman, 2018; Darniadi et al., 2019). Pulse proteins extracted from pea, lentil and faba bean have functional properties such as water holding, gelation, thickening, foam formation and stabilizing (Boye et al., 2010; Jarpa-Parra et al., 2015). Especially, replacement of dairy and animal protein sources with plant-based alternatives is currently gaining momentum due to vegan diets and environmental burden of high carbon footprint of animal products.

In current literature, there is no study about the utilization of faba bean concentrates as a foaming agent, and the powder production from *Malus floribunda* juice is also not yet been studied. Therefore, the main objectives of this study were; (1) evaluating the foam stability with incorporation of faba bean concentrate (FB) and maltodextrin (MD) as foaming agents, (2) thin layer foam-mat drying and mathematical modelling of the drying data, and (3) evaluating the effect of drying temperature and foam formulation on the powder properties of foam-mat dried *Malus floribunda* juice.

Materials and Methods

Materials

Fresh *Malus floribunda* fruits (average weight: 36.95±7.37 g) without any scar or blemish were collected from the cultivated plants that were grown in the yard of Hitit University in September, 2018. Maltodextrin with dextrose equivalent of 5-7 (Paselli™ MD6, Avebe Nisasta Ltd. Sti., Turkey) obtained from the local supplier. Faba bean protein concentrate with 60% (min.) protein and 9% (max.) moisture content - depending on the analysis of supplier- (VITESSENCE™ Pulse 3600, Ingredion, Germany) was kindly donated by Ingredion Germany GMBH. The chemical reagents namely; acetic acid (≥99.8%, Sigma Aldrich, Germany), hydrochloric acid (37-38%, Merck KGaA, Germany), KH_2PO_4 (≥99.5%, Merck KGaA, Germany), K_2HPO_4 (≥98%, Merck KGaA, Germany), potassium chloride (≥99.5%, Merck KGaA, Germany), and sodium acetate (≥99%, Merck KGaA, Germany) were purchased from local suppliers.

Production of *Malus floribunda* juice

Fresh fruits were washed with tap water and sliced for removing the seeds and stem. The juice of sliced fruit flesh was immediately extracted with a fruit juice extractor (AR 1060, Arzum Multivit, Turkey). The extracted juice was filtered through 500 micron filter and immediately filled into 200

ml glass bottles and the bottles were sealed with metal crown. The bottles were then heated up to 90°C in a water bath (Wise Bath, WB22, Daihan Scientific, South Korea) and hold at this temperature for 5 min for enzyme inactivation (Acar and Gokmen, 2000). Following the heat treatment, the bottles were immediately cooled to 4°C and stored at -18°C prior to the analysis.

Proximate analysis of materials

Moisture (method no: 934.01) by using a universal oven (Memmert, UN55, Germany), soluble solid (method no: 932.12) by using Abbe refractometer, pH (method no: 981.12) by using a pH meter (Adwa, AD1000, Hungary) and titratable acidity contents (method no: 942.15) of fruit juice, MD and FB were determined according to the standard methods of AOAC (2000).

Measurement of zeta potential (ζ)

1% (w/w, on water basis) FB was dissolved in Milli-Q water and stirred with a magnetic stirrer (Wisd, MSH20A, Korea) for 5h, and the mixture was kept at 4°C overnight for complete hydration (Ye at al., 2006). The zeta potential was measured between pH 2-9 according to the method of Gumus et al. (2017), in order to determine the isoelectric point and pH stability of faba bean protein concentrate. The protein sample was dissolved in the buffer solutions and then the zeta potentials were recorded with a Zeta sizer (Malvern Nano ZSP, UK).

Foam stability evaluation with experimental design

The experimental design shown in Table 1 was evaluated with Minitab Vers. 15 (Minitab Inc.) software by using response surface method and central composite design with two independent variables (FB and MD) at three different levels by keeping the whipping period as constant.

150 g of *Malus floribunda* juice with FB and/or MD were first mixed with a magnetic stirrer (Wisd, MSH20A, Korea) for 30 min, and then the mixture was whipped with a hand-blender at high speed (Arzum Pasto AR-183, Turkey) for 6 min to generate the foam depending on the preliminary foaming tests.

Table 1. Experimental design and the results of selected responses

Run order	FB% (w/w)	MD% (w/w)	Density (g/mL)	Overrun (%)
1	7.5	2.5	0.4138	108.05
2	10	0	0.3155	150.65
3	10	2.5	0.4083	114.06
4	7.5	2.5	0.4113	102.75
5	7.5	5	0.5381	63.89
6	7.5	2.5	0.4306	102.12
7	10	5	0.4285	113.44
8	5	5	0.6427	52.94
9	7.5	2.5	0.4221	104.95
10	7.5	0	0.3992	124.07
11	5	2.5	0.5601	78.14
12	7.5	2.5	0.4479	103.19
13	5	0	0.5711	88.30

The stability of the foams was determined by comparing the density and the overrun responses, and the experiments were performed as duplicate with at least three parallels (Baniel et al., 1997; Yang and Foegeding, 2010).

$$Density\ \left(^{g}/_{ml}\right) = \frac{foam\ weight\ (g)}{foam\ volume\ (ml)} \quad (1)$$

$$Overrun(\%) = \frac{(weight\ of\ 100\ ml\ mixture - wieght\ of\ 100\ ml\ foam)}{weight\ of\ 100\ ml\ foam} \quad (2)$$

The experimental design and statistical analysis of the obtained results were evaluated with Minitab Vers. 15 (Minitab Inc.).

Drying of *Malus floribunda* foams and thin layer modelling

The selected foam formulation (10%, w/w FB) together with the control (only fruit juice) and MD (10%, w/w) added sample was dried in a microwave oven that was set to 140 W power level (AWX-H20, Avox, Turkey) by continuous power application mode and air dried in a conventional built-in oven at 50, 60 and 70°C with 0.9 m/s airflow velocity (Samsung, model no: NV60K7140BB, Turkey). The oven temperature was set 15 min before drying, and the samples were placed on the middle rack in front of the fan of conventional oven.

The foam was spread evenly in glass petri dishes with 5 mm thickness, and the weight of petri dishes were recorded with an analytical balance (Precisa Gravimetrics XB220A, Switzerland) every 60 sec for microwave drying and every 10 min for air drying in order to determine the drying behaviour.

Moisture diffusion from the samples was evaluated according to the Fick's second law. The diffusion equation for an infinite slab for the falling rate period is shown in below equation (Cakmak et al., 2014);

$$MR = \frac{M - M_e}{M_0 - M_e} = \frac{8}{\pi^2}\sum_{n=0}^{\infty}\frac{1}{(2n+1)^2}exp\left[-(2n+1)^2\frac{\pi^2}{4}\frac{D_{eff}t}{L^2}\right] \quad (3)$$

here MR is dimensionless moisture rate, M_0 initial moisture content, M_e is equilibrium moisture content, M is the moisture at any time. L is the thickness of slab in m for evaporation occurs only from one side and D_{eff} represents the effective diffusion coefficient (m^2/s).

The models given in Table 2 were tested with MATLAB R2016a software (Mathworks, USA) using curve fitting toolbox. The goodness of fit was evaluated according to the model having the highest Adj-R^2 (adjusted correlation coefficient) together with the lowest SSE (sum of squared error) and RMSE (root mean square error).

$$adj - R^2 = 1 - (1 - R^2)\frac{N-1}{N-m-1}, R^2 = \frac{\sum_{i=1}^{N}(MR_i - MR_{pre,i}) \times \sum_{i=1}^{N}(MR_i - MR_{exp,i})}{\sqrt{\left[\sum_{i=1}^{N}(MR_i - MR_{pre,i})^2\right] \times \left[\sum_{i=1}^{N}(MR_i - MR_{exp,i})^2\right]}} \quad (4)$$

$$SSE = \sum_{i=1}^{n}(MR_{exp,i} - MR_{pre,i})^2 \quad (5)$$

$$RMSE = \left[\frac{1}{N}\sum_{i=1}^{N}(MR_{exp,i} - MR_{pre,i})^2\right]^{0.5} \quad (6)$$

where $MR_{pre,i}$ expresses the predicted and $MR_{exp,i}$ expresses the experimental moisture ratio, N is the number of observations, m is number of regression parameters, and n is the number of constants.

Powder properties

The flowability and cohesiveness of obtained fruit powders were determined by Carr index (CI) and Hausner ratio (HR), respectively according to the following equations (Jinapong et al., 2008);

$$CI = \frac{(\rho_{tapped} - \rho_{bulk})}{\rho_{tapped}} \times 100 \quad (7)$$

$$HR = \frac{\rho_{tapped}}{\rho_{bulk}} \quad (8)$$

Table 2. Tested thin layer models

Model no	Model name	Model equation	Reference
1	Lewis	$MR = e^{(-kt)}$	Cakmak et al. (2014); Kucuk et al. (2014)
2	Page	$MR = e^{(-kt^n)}$	
3	Henderson & Pabis	$MR = ae^{(-kt)}$	
4	Logarithmic	$MR = ae^{(-kt)} + c$	
5	Two-term	$MR = ae^{(-k_0 t)} + be^{(-k_1 t)}$	
6	Midilli *et al.*	$MR = ae^{(-kt^n)} + bt$	
7	Modified Midilli *et al.*	$MR = e^{(-kt^n)} + bt$	

Colour and anthocyanin content analysis

The colour of raw materials and the dried samples were measured with a spectrophotometer (Konica Minolta, CM3600D, Japan) using CIE L*a*b* colour scale. In this scale, the lightness (L*) is given as L*=0 being black, L*=100 being white, redness-greenness (a*) is given as a*<0 being green, and a*>0 being red, and yellowness-blueness (b*) is given as b*<0 being blue, and b*>0 being yellow, respectively. The hue angle (h*) is calculated according to the following equation;

$$h^* = tan^{-1}\left(\frac{b^*}{a^*}\right) \quad (9)$$

The total monomeric anthocyanin content was determined according to the pH differential shift method. The anthocyanin content was expressed as mg cyanidin-3-galactoside/ kg dm (Coklar et al., 2018).

$$\frac{mg\ cya-3-galactoside}{kg\ dm} = \frac{\left[(A_{\lambda max} - A_{700})_{pH1} - (A_{\lambda max} - A_{700})_{pH4.5}\right] \times MW \times df \times 1000}{\varepsilon \times d \times E} \quad (10)$$

here A represents absorbance, MW is the molecular weight of cya-3-galactoside (448.84 g/mol), df is the dilution factor, ε is the molar absorbance of cya-3-galactoside (34300 lt/mol.cm), d is the cell path length of cuvette (1 cm) and E is the sample weight (kg/lt solvent).

Statistical Analyses

The experimental design was evaluated with Minitab Vers. 15 (Minitab Inc., USA) and nonlinear regression of thin layer modelling was performed with MATLAB R2016a (Mathworks, USA). The statistical analysis of the results colour and anthocyanin content was performed by using SPSS 16.0 software (SPSS Inc., USA) according to one-way ANOVA and applying Duncan test with a significance level of 95%.

RESULTS AND DISCUSSION

Proximate analysis of materials and zeta potential

The proximate composition of *Malus floribunda* juice was determined as; 80.02±0.26% moisture, the soluble solid content was 18.90±0.10 °Bx, the titratable acidity 2.38±0.03% malic acid equivalent and the pH was 2.91±0.02. The moisture of FB was found as 7.16±0.3%, and the moisture of MD was 7.59±0.03%, respectively.

The zeta potentials of FB had positive potential (6.59-25.5 mV) below the isoelectric point (pH= 4.45), whereas above the isoelectric point, negative potentials (-20.6/-6.38 mV) were obtained. Similar trend in electrostatic charge was observed in the literature for the faba bean proteins (Gumus et al., 2017) and lentil proteins (Jarpa-Parra et al., 2015). The repulsive forces improve the protein stability below and above the isoelectric points, so that the solubility of plant proteins is high at these aforementioned pH values (Gumus et al., 2017). Therefore, at the natural pH of MF juice, the proteins did not precipitate and there was no need for pH adjustment before the foaming process.

Evaluation of the experimental design

The stability of MF juice foams was evaluated at the 95% level, and the results of the responses are shown in Table 1, and regression analyses are in Table 3 and 4. The significant parameters that improved the density response were given in Equation (10). In addition to the regression analysis, the linear and square interaction terms had significant effect (P <0.05) on density according to ANOVA results (not shown in here).

$$density = 1.109 - 0.143 \times FB\% + 0.007 \times FB\%^2 \quad (11)$$

The lower foam density is associated with higher air incorporation into the structure and so the higher overrun are obtained (Boye et al., 2010; Jarpa-Parra et al., 2015; Ayetigbo et al., 2019). The stable foams are created by the transfer of the protein into the air-water interface that is acting as a stabilizer therefore preventing the foam collapse (Jarpa-Parra et al., 2015; Ayetigbo et al., 2019). The lowest average density (0.3155 g/mL) and the highest overrun (150.65%) values had been reached at the 10% FB level (Table 1, run order 2). The maximum foam stability was also shown in the surface plot (with arrow) with respect to FB and MD content versus density or overrun responses in Figure 1 and Figure 2. Therefore, the FB protein was quite successful in MF juice foam stabilization, especially at the highest level of incorporation (10%) according to the regression analysis. The egg albumen or particularly ovalbumin is generally employed in foam-mat drying of several food substances (Franco et al., 2016; Dehghannya et al., 2018; Ng and Sulaiman, 2018), however non-animal protein sources such as; lentil (Jarpa-Parra et al., 2015) and faba bean (present study) had a great potential to improve the foam stability as well. Consequently, the vegan or vegetarian friendly foam-mat dried food materials can be developed by the faba bean proteins.

Table 3. Regression coefficients of density response

Term	Coeff	SE Coef	T	P
Constant	1.10888	0.143180	7.745	0.000
FB%	-0.14306	0.038854	-3.682	0.008
MD%	-0.01088	0.020827	-0.522	0.618
FB% × FB%	0.00650	0.002550	2.549	0.038
MD% × MD%	0.00401	0.002550	1.572	0.160
FB% × MD%	0.00165	0.002119	0.780	0.461

Adj-R^2 = 91.33%, S = 0.0264845, PRESS = 0.0389263

Table 4. Regression coefficients of overrun response

Term	Coeff	SE Coef	T	P
Constant	0.348442	0.498485	0.699	0.507
FB%	0.123218	0.135269	0.911	0.393
MD%	-0.060805	0.072509	-0.839	0.429
FB% × FB%	-0.001035	0.008877	-0.117	0.910
MD% × MD%	-0.004429	0.008877	-0.499	0.633
FB% × MD%	-0.000740	0.007553	-0.100	0.923

Adj-R^2 = 86.86%, S = 0.0922061, PRESS = 0.530487

In contrast to FB, the MD incorporation into foam formulation had no significant effect on both density and overrun responses (P >0.05). The regression analysis together with the ANOVA results was significant in terms of high Adj-R^2 and P<0.05 of overrun response, respectively, but the FB and MD had no significant effect individually, square or interaction state. Despite being used as a wall material or carrier agent in the foam-mat drying, the effects of maltodextrin in foam stability was not discussed in the recent literature (Seerangurayar et al., 2017; Ng and Sulaiman, 2018). But since the MF juice is rich in bioactive compounds, 10% MD was also used as a wall material in further foam-mat drying step in order to encapsulate the bioactive components and to compare the drying behaviour with control (no FB or MD) sample and 10% FB-foamed juices.

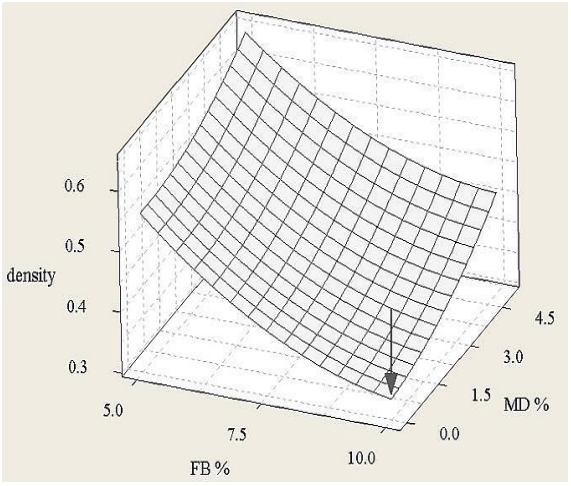

Figure 1. 3D surface plot of density versus FB and MD percent

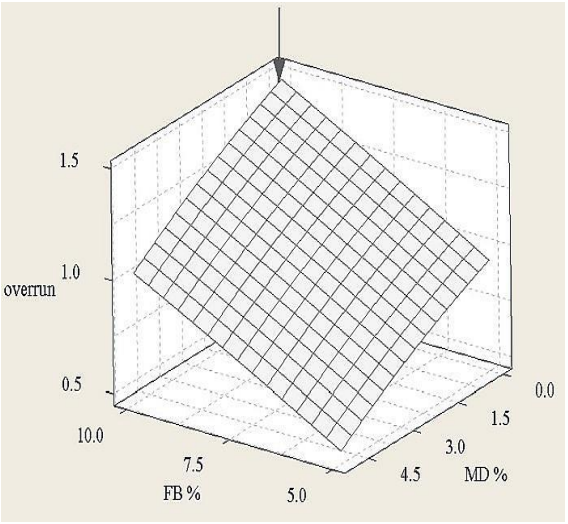

Figure 2. 3D surface plot of overrun versus FB and MD percent

Drying behaviour and mathematical modelling

The initial average moisture of control sample was reduced from 4.2491 kg water/kg dm to 0.0701 kg water/kg dm with drying; while 10% FB-foamed sample was reduced from 2.6734 kg water/kg dm to 0.0645 kg water/kg dm; and 10% MD added sample was reduced from 2.6663 kg water/kg dm to 0.0937 kg water/kg dm. Since the addition of FB and MD had lowered the moisture content of the neat fruit juice, the initial dry matter content of 10% FB and MD samples were obtained higher than the control sample. The final moisture contents of dried samples were similar or even lower than the guar gum-xanthan gum foamed date pulp and egg albumen foamed yacon juice powders (Franco et al., 2016; Seerangurayar et al., 2017).

The control (no FB or MD-added) sample had same drying behaviour for air drying and microwave drying, and both the constant-rate period and falling-rate period appeared on the drying rate curves. However, 10% MD-added sample and 10% FB foamed samples had two falling-rate periods with different slopes in air drying process at 50, 60 and 70°C. In contrast, these samples had a constant and a falling-rate period in the microwave drying like control sample.

The moisture transfer rate from the foam samples were significantly improved by foam-mat drying method (Figure 1). Depending on the drying temperature or power, the drying period had been reduced between 20-43% for 10% FB samples compared to the control. Same behaviour was observed in the egg albumen-sorbitan monostearate foamed mango pulp drying (Chaux-Gutiérrez et al., 2017) and egg albumen-methylcellulose foamed apple juice drying (Kudra and Ratti, 2006). Therefore, the incorporation of air bubbles formed during foaming process provided faster moisture transfer vis-à-vis the other samples (Kudra and Ratti, 2006; Hardy and Jideani, 2017). Interestingly, the drying period was also reduced for 10% MD-added sample between 7-11%. This reduction could be due to the increased dry matter content by the addition of maltodextrin.

The experimental dimensionless moisture ratio that was fitted to the mathematical models given in Table 2, and the results of the nonlinear regression analysis were given in Table 5a and 5b. The tested models had high correlations with the experimental data, and the Adj-R^2 values were found between 0.9256-0.9999. Among them, Midilli *et al.* model was the most successful model representing the drying behaviour of MF juice independent of the drying temperature/power or the formulation.

Table 5. a. Regression parameters of tested mathematical models

Sample	Model	50°C	60°C	70°C	140 W
Control	Lewis	SSE=0.08041, Adj-R^2=0.9743, RMSE=0.05788	SSE=0.06732, Adj-R^2=0.9721, RMSE=0.06293	SSE=0.03182, Adj-R^2=0.9828, RMSE=0.04948	SSE=0.32850, Adj-R^2=0.9319, RMSE=0.09422
	Page	SSE=0.03548, Adj-R^2=0.9882, RMSE=0.03928	SSE=0.01500, Adj-R^2=0.9934, RMSE=0.03062	SSE=0.00786, Adj-R^2=0.9954, RMSE=0.02559	SSE=0.01560, Adj-R^2=0.9967, RMSE=0.02080
	Henderson and Pabis	SSE=0.07337, Adj-R^2=0.9755, RMSE=0.05648	SSE=0.05801, Adj-R^2=0.9745, RMSE=0.06021	SSE=0.02477, Adj-R^2=0.9855, RMSE=0.04543	SSE=0.22570, Adj-R^2=0.9519, RMSE=0.07919
	Logarithmic	SSE=0.08328, Adj-R^2=0.9722, RMSE=0.06018	SSE=0.05884, Adj-R^2=0.9741, RMSE=0.06064	SSE=0.03048, Adj-R^2=0.9821, RMSE=0.05039	SSE=0.22570, Adj-R^2=0.9519, RMSE=0.07920
	Two-term	SSE=0.07337, Adj-R^2=0.9732, RMSE=0.05911	SSE=0.05008, Adj-R^2=0.9748, RMSE=0.05981	SSE=0.02477, Adj-R^2=0.9826, RMSE=0.04977	SSE=0.22600, Adj-R^2=0.9490, RMSE=0.08153
	Midilli et al.	SSE=0.02346, Adj-R^2=0.9918, RMSE=0.03265	SSE=0.01211, Adj-R^2=0.9943, RMSE=0.02841	SSE=0.00706, Adj-R^2=0.9955, RMSE=0.02533	SSE=0.01100, Adj-R^2=0.9976, RMSE=0.01775
	Modified Midilli et al.	SSE=0.03692, Adj-R^2=0.9877, RMSE=0.04006	SSE=0.01737, Adj-R^2=0.9924, RMSE=0.03295	SSE=0.00973, Adj-R^2=0.9943, RMSE=0.02847	SSE=0.01560, Adj-R^2=0.9967, RMSE=0.02080

Table 5. a. (continued)

Sample	Model	50°C	60°C	70°C	140 W
10% FB	Lewis	SSE=0.02928, Adj-R²=0.9878, RMSE=0.03827	SSE=0.02232, Adj-R²=0.9913, RMSE=0.03428	SSE=0.00354, Adj-R²=0.9976, RMSE=0.01717	SSE=0.26570, Adj-R²=0.9256, RMSE=0.09572
	Page	SSE=0.02247, Adj-R²=0.9902, RMSE=0.03439	SSE=0.00290, Adj-R²=0.9988, RMSE=0.01270	SSE=0.00125, Adj-R²=0.9991, RMSE=0.01065	SSE=0.01110, Adj-R²=0.9968, RMSE=0.01992
	Henderson and Pabis	SSE=0.02882, Adj-R²=0.9874, RMSE=0.03895	SSE=0.01519, Adj-R²=0.9937, RMSE=0.02905	SSE=0.00303, Adj-R²=0.9978, RMSE=0.01660	SSE=0.18380, Adj-R²=0.9467, RMSE=0.08102
	Logarithmic	SSE=0.03415, Adj-R²=0.9850, RMSE=0.04240	SSE=0.01946, Adj-R²=0.9920, RMSE=0.03288	SSE=0.00300, Adj-R²=0.9978, RMSE=0.01651	SSE=0.18380, Adj-R²=0.9467, RMSE=0.08103
	Two-term	SSE=0.02883, Adj-R²=0.9859, RMSE=0.04118	SSE=0.01948, Adj-R²=0.9909, RMSE=0.03490	SSE=0.00226, Adj-R²=0.9979, RMSE=0.01585	SSE=0.18400, Adj-R²=0.9425, RMSE=0.08413
	Midilli et al.	SSE=0.01811, Adj-R²=0.9916, RMSE=0.03172	SSE=0.00257, Adj-R²=0.9989, RMSE=0.01229	SSE=0.00110, Adj-R²=0.9991, RMSE=0.01049	SSE=0.00860, Adj-R²=0.9974, RMSE=0.01787
	Modified Midilli et al.	SSE=0.02388, Adj-R²=0.9895, RMSE=0.03545	SSE=0.00290, Adj-R²=0.9988, RMSE=0.01270	SSE=0.00128, Adj-R²=0.9991, RMSE=0.01077	SSE=0.01110, Adj-R²=0.9968, RMSE=0.01992
Sample	Model	50°C	60°C	70°C	140 W
10% MD	Lewis	SSE=0.10040, Adj-R²=0.9732, RMSE=0.05785	SSE=0.05434, Adj-R²=0.9794, RMSE=0.05348	SSE=0.01240, Adj-R²=0.9928, RMSE=0.03088	SSE=0.29990, Adj-R²=0.9304, RMSE=0.09391
	Page	SSE=0.06057, Adj-R²=0.9832, RMSE=0.04570	SSE=0.00941, Adj-R²=0.9962, RMSE=0.02287	SSE=0.00019, Adj-R²=0.9999, RMSE=0.00399	SSE=0.00890, Adj-R²=0.9979, RMSE=0.01641
	Henderson and Pabis	SSE=0.09954, Adj-R²=0.9725, RMSE=0.05859	SSE=0.03828, Adj-R²=0.9847, RMSE=0.04611	SSE=0.00395, Adj-R²=0.9975, RMSE=0.01814	SSE=0.20430, Adj-R²=0.9512, RMSE=0.07868
	Logarithmic	SSE=0.09839, Adj-R²=0.9728, RMSE=0.05825	SSE=0.03176, Adj-R²=0.9873, RMSE=0.04200	SSE=0.00645, Adj-R²=0.9959, RMSE=0.02320	SSE=0.20430, Adj-R²=0.9512, RMSE=0.07869
	Two-term	SSE=0.08435, Adj-R²=0.9767, RMSE=0.05393	SSE=0.03176, Adj-R²=0.9865, RMSE=0.04322	SSE=0.00646, Adj-R²=0.9951, RMSE=0.02541	SSE=0.20430, Adj-R²=0.9480, RMSE=0.08118
	Midilli et al.	SSE=0.02477, Adj-R²=0.9929, RMSE=0.02974	SSE=0.00653, Adj-R²=0.9972, RMSE=0.01960	SSE=0.00015, Adj-R²=0.9999, RMSE=0.00393	SSE=0.00560, Adj-R²=0.9986, RMSE=0.01323
	Modified Midilli et al.	SSE=0.05046, Adj-R²=0.9860, RMSE=0.04171	SSE=0.00817, Adj-R²=0.9967, RMSE=0.02131	SSE=0.00019, Adj-R²=0.9999, RMSE=0.00411	SSE=0.00890, Adj-R²=0.9979, RMSE=0.01641

Table 5b. The coefficients of best fitting mathematical model

Sample	Temperature/ power	Midilli *et al.* model constants
Control	50°C	a=0.9405, b=9.129×10^{-13}, k=0.00018, n=1.506
	60°C	a=0.9651, b=4.244×10^{-13}, k=0.00041, n=1.494
	70°C	a=0.9768, b=3.611×10^{-14}, k=0.00262, n=1.315
	140 W	a=0.9695, b=3.723×10^{-12}, k=2.084×10^{-6}, n=1.828
10% FB	50°C	a=0.9513, b=1.528×10^{-12}, k=0.00175, n=1.223
	60°C	a=0.9856, b=2.225×10^{-14}, k=0.00297, n=1.232
	70°C	a=0.9971, b=2.221×10^{-14}, k=0.01122, n=1.077
	140 W	a=0.9755, b=5.748×10^{-13}, k=3.009×10^{-6}, n=1.851
10% MD	50°C	a=0.9709, b=2.224×10^{-14}, k=0.00016, n=1.556
	60°C	a=0.9712, b=3.939×10^{-13}, k=0.00109, n=1.360
	70°C	a=1.0010, b=1.369×10^{-7}, k=0.00666, n=1.192
	140 W	a=0.9737, b=3.439×10^{-11}, k=2.383×10^{-6}, n=1.834

Powder properties

The flowability of dried MF juice samples were evaluated according to Carr index and Hausner ratio, however these values for control and MD-added MF juices could not be calculated due to their sticky and agglomerated structure. The sugar content of MF juice and comparably higher drying periods of these samples may be resulted in the poorly flowable and highly adhesive structure of final powders (Jinapong et al., 2008; Seerangurayar et al., 2017; Varhan and Koç, 2017). Besides, high sugar content may decrease the glass transition temperature and initiate caking of powders following the sugar crystallization (Jinapong et al., 2008). Also the hygroscopicity of powders may be increased due to the reduction of the glass transition temperature, and thus the flowability of the powders might be affected negatively (Seerangurayar et al., 2017). On the other hand, FB foamed samples had an average Carr indexes between 17.3-26.0%, while the Hausner ratio was found between 1.21-1.35. Therefore, the powders had "fair" to "good" flowability, while the cohesiveness was classified between "intermediate-low" to "intermediate" (Jinapong et al., 2008; Seerangurayar et al., 2017; Dehghannya et al., 2018). The increment of the drying temperature resulted in lower Carr index and Hausner ratio analogous to the results of foam mat dried lime juice and muskmelon powders (Asokapandian et al., 2016; Dehghannya et al., 2019).

Colour and anthocyanin content of samples

The colour values of the dried samples were compared according to the drying temperature/power and the results were shown in Table 6. The lowest L*, a*, b* and h* values were obtained for the microwave dried samples independent of the sample formulation (P <0.05). Although the drying period at 50°C was higher than the other drying temperature or power levels, the lightness of control and the 10% MD added samples had significantly the highest values compared to other temperature/power levels (P <0.05). This could be due to browning of the dried sample at the elevated temperatures (Asokapandian et al., 2016; Dehghannya et al., 2018; Dehghannya et al., 2019). Besides, the highest lightness values were observed for the 10% FB foamed sample at all temperature and 140 W power level (P <0.05). Because of the air incorporation due to the foam formation, the lightness values of FB foamed powders might be higher compared to the control and MD-added samples (Asokapandian et al., 2016).

The redness values of dried powder are associated with the potential of the MF juice as a natural colorant. The colour values of fresh MF juice (after heat treatment at 90°C) was found as; L*: 28.45±0.09, a*:17.69±0.28, and b*: 6.26±0.13. The colour values were similar to those given in the study of Coklar et al. (2018). The redness intensity of 10% FB powders increased with the increasing of the drying temperature contrary to

the control and 10% MD powders (P <0.05). Also, the highest redness in 10% FB powders was obtained from 70°C air drying and 140 W microwave drying. The redness reduction in control and 10% MD samples were probably associated with the temperature sensitivity of anthocyanins (Ng and Sulaiman, 2018). Nevertheless, 10% FB powders did not have a similar trend for a* reduction with respect to temperature. This behaviour might be related to the shorter drying times for 70°C (240 min) and 140 W (36 min) powders in comparison with the control and 10% MD samples. Hue angles of the control and 10% MD samples dried in microwave oven were lower than the flesh of fresh *Malus floribunda coccinella* (12.47±0.81) fruit, but also h* of fresh MF juice (19.50±0.10) and the rest of the dried samples were higher than this given study (Coklar et al., 2018). This variation in h* value might be associated with the variety of the fruit, the effect of heat treatment or drying and mixing with soluble ingredients like FB or MD.

Table 6. Colour values of dried powders

Sample	Temperature/ power	L*	a*	b*	h*
Control	50°C	$31.16^{c, A}$	$22.15^{c, B}$	$5.70^{b, A}$	$14.38^{b, A}$
	60°C	$29.20^{b, A}$	$19.73^{b, A}$	$5.68^{b, A}$	$16.08^{c, A}$
	70°C	$29.39^{b, A}$	$19.02^{b, A}$	$5.45^{b, A}$	$16.01^{c, A}$
	140 W	$25.08^{a, A}$	$5.12^{a, B}$	$0.79^{a, A}$	$8.73^{a, A}$
10% FB	50°C	$43.17^{a, C}$	$14.08^{a, A}$	$5.16^{a, A}$	$20.07^{a, C}$
	60°C	$64.83^{d, C}$	$17.65^{b, A}$	$7.99^{c, B}$	$24.35^{b, B}$
	70°C	$60.84^{b, C}$	$18.68^{c, A}$	$8.74^{d, C}$	$25.08^{b, B}$
	140 W	$62.93^{c, C}$	$18.85^{c, C}$	$6.73^{b, B}$	$19.63^{a, B}$
10% MD	50°C	$32.40^{b, B}$	$26.22^{c, C}$	$7.80^{c, B}$	$16.54^{b, B}$
	60°C	$32.70^{b, B}$	$26.31^{c, B}$	$8.01^{c, B}$	$16.92^{b, A}$
	70°C	$31.00^{b, B}$	$22.84^{b, B}$	$6.45^{b, B}$	$15.71^{b, A}$
	140 W	$28.52^{a, B}$	$3.99^{a, A}$	$0.55^{a, A}$	$7.97^{a, A}$

[a-d]Different letters in the same column are statistically different (P <0.05).
[A-C]Different letters in the same row are statistically different (P <0.05).

The anthocyanins are the source of purple to red colours in berries and skin of apples. Unlike commercial apple cultivars, *Malus floribunda* apple is distinguished with both red skin and the flesh colour that reflects the presence of anthocyanin pigments in the flesh as well (Coklar et al., 2018). The total anthocyanin content of the samples determined according to pH differential shift method was given in Figure 3. Depending on the lack of flowability of control and 10% MD-added samples, only the anthocyanin content of 10% FB powders were determined. The fresh juice had significantly the highest anthocyanin (P <0.05), while the drying temperature increment reduced the total anthocyanin content. This is due to the fact that the drying temperature and drying period significantly affect the level of anthocyanin degradation (Patras et al., 2010; Zheng et al., 2011; Darniadi et al., 2019), and the redness values associated with the anthocyanin pigments decreases due to the effect of drying (Ng and Sulaiman, 2018). However, the redness of 10% FB powders did not follow the same trend. The redness values increased with respect to increasing the drying temperature, while the anthocyanins gradually decreased with respect to temperature. But the anthocyanin content of microwave dried foams was in the same group with the sample dried at 60°C (P >0.05). The stability of anthocyanins is also effected by some

intrinsic parameters such as the presence of proteins, metal ions, pH, soluble solid content and sugar moieties attached to the phenolic ring etc. (Patras et al., 2010). Thus, the combination pH and high temperature may result in sudden drop of total monomeric anthocyanin content for the powders that were dried over 50°C.

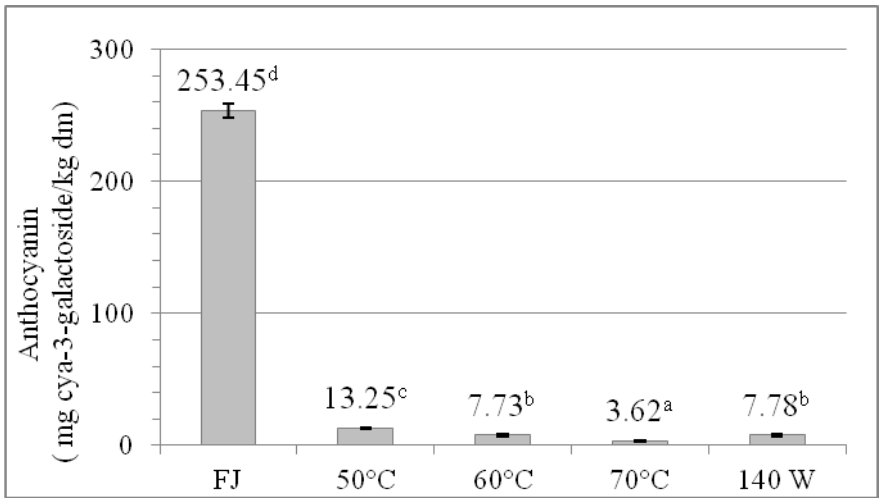

Figure 3. Total anthocyanin content of fresh juice (FJ) and 10% FB dried foams

CONCLUSIONS

In this study, foam-mat drying behaviour of *Malus floribunda* fruit juice by air drying at different temperatures (50, 60 and 70°C) and microwave drying at 140 W was evaluated. The foam stability was improved by the increasing level of FB, and 10% (w/w) FB had the highest foam stability. The drying period was significantly reduced by foam-mat drying application, and also the lowest drying period was observed in microwave drying. The Midilli *et al.* model had the highest Adj-R^2 with the lowest SSE and RMSE regarding the regression analysis independent of the foam formulations or the drying conditions.

The powders of 10% FB from each drying condition had a highly flowable structure with the highest lightness values compared to the control and 10% MD-added samples. Besides, the redness of 10% FB powders was not adversely affected from the drying temperature increment. The anthocyanin contents of 10% FB powders were significantly lower than the fresh juice (P <0.05), but the anthocyanin amount of powders dried at the 50°C was the highest among other powders.

Foam-mat drying is an energy saving drying method, but microwave assisted foam-mat drying had even better results in reduction of drying period, as well as the preserving the bioactive compounds and improving the powder flowability. Also, FB was successful for production of stable foams from the highly acidic MF juice. Therefore, a novel natural red food colorants or instant juice powders that can be utilized in vegan and vegetarian food formulations were developed from the MF juices by FB proteins with foam-mat microwave drying method.

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