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INFLUENCE OF FOAMING AGENTS ON FOAMING PROPERTIES OF NAGPUR MANDARIN JUICE AND EFFECT OF MICROWAVE-ASSISTED FOAM MAT DRYING ON DRYING CHARACTERISTICS

Bhagyashree N. Patil[1]*, Suchita V. Gupta[1] And Nivrutti B. Patil[2]
1. Department of Agricultural Process Engineering, Dr. PDKV, Akola Maharashtra, India,
2. Krishi Vigyan Kendra Karda Risod, Maharashtra, India.

Abstract:
Limonin and nomilin are present in Nagpur mandarin fruit/ juice which gives bitterness to juice cause off-flavor therefore processing on Nagpur mandarin fruit is limited hence the present study was undertaken to prepare Nagpur mandarin juice powder. For the present study different levels of SPI (3 to 9%), GMS (0.3 to 0.9%), CMC (0.3 to 0.9%), sugar (5 to 15%) and whipping time 3 to 9 min were taken, The CCD design (Design expert software version 11.0.4.1, Statease Inc, Minneapolis, United States) used for the optimization of foaming properties of Nagpur mandarin juice. After optimization of foaming properties, the foamed juice was dried at different microwave power from 180 to 900 W and 2 to 6 mm drying bed thickness to study the drying characteristics and empirical models. The optimized conditions for Nagpur mandarin juice foaming were soy protein isolate (2.10%), sugar content (5.10%), Glycerol Mono Stearate (2.75%), Carboxy Methyl Cellulose (1.75%) and whipping time 8 min. The drying time was found 18 min to 58 min with the final moisture content of 4.77 to 1.39% (db). The D_{eff} values are ranged from 0.99 x 10^{-9} to 14.60 x 10^{-9} m^2/s and the activation energy was ranged from 19.54 to 17.48 W/g for 2 to 6 mm drying bed thickness.

Keywords: GMS, sugar, Microwave power, Nagpur mandarin, Soy protein isolate

Abbreviations: GMS (Glycerol monostearate), CMC (Carboxy methyl cellulose), SPI (Soy Protein Isolate), WT (Whipping time)

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Correspondence author: Bhagyashree Nivrutti Patil bhagyashreepatil@pdkv.ac.in, bhagyashreepatil21@gmail.com

Introduction:

Citrus reticulata (Mandarin orange) is a cluster of thin slack orange peels mostly cultivated in India. China is the leading producer of citrus (29.56 million tons), followed by Brazil (18.96 million tons) and India is the third most important in citrus (12.74 million tonnes) with an overall area of 10.55 million hectares (14.9% of the fruit surface) and a productivity 10.4 MT/ha. Nagpur *Santra* is a very fine variety and is widely popular for its good quality in India as well as in the world. Maharashtra is the country's main state producing mandarin with an area of 0.135 million

hectares (40.9 percent), estimated production of 7.42 million tons (21.61 percent) and productivity of 9 MT / ha.

Foam-mat drying is one of the enticing emerging technologies in the aqueous food sector. In this process fluid or semi-liquid is converted into stable foam and then thermally dehydrated. As a result, the surface area of the material to be dried is enhanced by the addition of air/gas with foaming agents to form a stable sponge through moderate thermal treatment, drastically reducing the drying time (Shaari et al. 2017). The drying process of the foam mat preserves the natural composition of fresh produce as colour, flavor and consumer acceptability due to less heat damage, as mentioned in the Kadam and Balasubramanian (2011) and Rajkumar et al. (2007). Foegeding et al. (2006) seem to be a factor in the essence of foams, and physical attributes are of significance in drying moisture. The method of foam mat drying provides a variety of opportunities in the fruit sector wherein viscous and messy food/juice are complicated to dry without reducing the quality. Some investigation carried out on various fruits by researchers such as guava (Qadri and Srivastava 2015), muskmelon (Sangamithra et al. 2015), tomato juice (Kadam and Balasubramanian 2011), bael fruit pulp (Bag et al. 2009), apple juice (Raharitsifa et al. 2006) and banana (Thuwapanichayanan et al. 2012).

Electromagnetic waves are used in Microwave drying technology was proposed in a conventional microwave oven. The interior temperature of samples also can be controlled within a proper range, which was beneficial to retaining the nutrient and flavor of dried products (Dehghannya et al. 2018). Many empirical models were introduced with good fitness difficult to link the drying situation and products of these models and the entire process was taken into account. In addition, the absence of physical significance limits the role and applicability of those models. Empirical equations discussing the exchange of moisture between the thin layer of its drying variable and its surrounding air are crucial for drying modeling. Due to the influence of one or more variables in such models, the criteria can be identified as a feature of drying conditions (Jurendic 2012).

Heat-sensitive food products, including fruit juices, have received reports of foam-mat drying in which the drying intensity improves and the drying period significantly increases the visual, nutritional and sensory characteristics of the product. Other drying methods, such as drums and spray drying, also affect the cost of the product. Thus, a microwave drying method in combination with foam mat drying, in which foam is formed by the addition of a foaming agent, has had a less drying effect. Sugar has anti-bittering characteristics and is hence incorporated in the present study. There has been very limited research regarding the drying of mandarin fruit juice. Therefore, the present study was carried out with the aim of developing Nagpur mandarin juice powder using foam mat drying and empirical model fitting during electromagnetic wave drying.

Materials and methods:

The fully ripe Nagpur mandarin fruit from the Department of Horticulture, Dr. PDKV, Akola was taken for experimentation. The fruit was peeled then used for the extraction of juice in a juicer (Bajaj JEX 16 800 W Juicer). Fresh juice was blanched at 95 ^{o}C for 1 min (Shaari et al. 2017) to inactivate the enzyme and cooled quickly. The 100 g Nagpur mandarin juice was taken in a 200 ml beaker and addition of soy protein isolate (3, 6 and 9%), GMS (2, 3.5 and 5%), CMC (1, 2 and

3%), sugar content (5, 10 and 15%), in given different proportions. The mixture was whipped with a hand blender (ORPAT model: HHB 100E, India) for foam generation for 3, 6 and 9 min at 1400 rpm.

A) **Foaming Properties**

The foaming properties were optimized in order to maximize foam expansion (stretching) and longer foam cycles (stability) with minimum foam density. The optimum condition of foaming was considered for the production of Nagpur mandarin powder. The expansion of foam shows the amount of air incorporated during whipping in the juice and was measured with the initial volume before foaming and final volume after foaming (Eqn 1). For calculating foam density, the foamed juice was poured into a measuring cylinder of 200 ml without trapping the air voids and also without breaking down the foam structure. The density was calculated (g/cc) in terms of mass by volume (Eqn 2). The stability is measuring foam drainage is usually the easiest way to assess the quality of foam. The drainage test was performed on the basis of the method to foam stability (Eqn 3) (Bag et al. 2009, Sangamithra *et al.* 2015; Sharri 2017; Khodifad and Kumar 2019).

$$\text{Foam expansion (\%)} = \frac{V_1 - V_0}{V_1} \times 100 \quad (1)$$

$$\text{Foam density} = \frac{\rho V_0}{V_1} \times 100 \quad (2)$$

$$\text{Foam stability} = \frac{ILV - D}{ILV} \times 100 \quad (3)$$

Where V_0 and V_1 is the initial and final volume of Nagpur mandarin juice (cm^3), ILV is the volume of the initial liquid phase (ml) and DV is the volume of drainage (ml)

The Central Composite Design (CCD) in design expert software under response surface methodology (version 11.0.4.1, Statease Inc, Minneapolis, United States) was used for testing, which includes 28 runs with 5 center points. Regression analysis was tested for each response and evaluates the statistical significance. Lack of fit test and R^2 (determination coefficient) were tested to verify the validity of the regression model. A successful model should have a greater R^2 and fitness that is not significant. Analysis of the surface response, mapping of plots and optimization of the response were carried out.

(B) Microwave drying of foamed mandarin juice

The microwave oven (LG model MC=9280XC) was used to dry foamed Nagpur mandarin juice. The foam (prepared using optimized condition) was uniformly spread over a plate lined with teflon and a drying process was performed. The drying experiment was performed from 180 to 900 W of microwave power and the 2 to 6 mm drying bed thickness for determining the drying time. For the determination of empirical equation, drying characteristics the weight of the plate was measured until the constant weight was reached at a minute interval using electronic balancing. The moisture content of the foamed juice was calculated using the hot air oven method at 105 ± 2 ºC for 24 h (Horwitz, 2005). The drying rate and moisture ratio were determined using eqn (4) and Eqn (5) (Khodifad and Kumar 2019; Franco et al. 2015).

$$R = \frac{\text{WML (kg)}}{\text{Time interval (min) x DM (kg)}} \quad (4)$$

$$MR = \frac{M - M_\infty}{M_o - M_\infty} \quad (5)$$

Where, WML is the initial weight of sample – the weight of the sample after time θ, M is moisture content at any time, % (db), M_o and M_∞ are initial and equilibrium moisture content, % (db)

c) **Effective Moisture diffusivity (D_{eff}) and activation energy**

In drying, diffusivity is used to indicate the flow of moisture or moisture out of material. In the falling rate period of drying, moisture is transferred mainly by molecular diffusion. Diffusivity is influenced by shrinkage, case hardening during drying, moisture content and temperature of the material. The moisture diffusivity of the samples was estimated by using the simplified mathematical Fick's second diffusion model.

$$M_R = \frac{M - M_e}{M_0 - M_e} = \frac{8}{\pi^2} \sum_{n=1}^{\infty} \frac{1}{(2n+1)^2} \exp\left[\frac{-(2n+1)^2 \pi^2 D_{eff} t}{4H^2} \right] \quad (6)$$

Equation (6) is simplified and given below. The effective diffusivity was related with the microwave power during microwave drying.

$$D_{eff} = D_0 \exp\left(\frac{-E_a\, m}{R_g P}\right) \quad (7)$$

Where D_0 is the constant in the Arrhenius equation (m^2/s), E_a is the activation energy (W/g), m is the mass of sample in g, P is the microwave power (W) and R is the universal gas constant (kJ / mol K).

Eqn(7) is rearranged in the form of :

$$\ln(D_{eff}) = \ln(D_0) \frac{-E_a}{R_g P} \quad (8)$$

The activation energy was calculated by plotting a curve between ln (D_{eff}) v/s 1/P.

Results and Discussion:

Foam expansion, density and stability

The results for foam expansion (36.25 – 15.25%), foam density (0.61 – 0.82 g/cc) and foam stability (74.37 – 94.37%) of the foamed Nagpur mandarin juice are presented in Fig 1.

To represent the cumulative influence of five variables on the expansion of foams, two variables were generated for the corresponding model, the reaction surface and the contour plots (Fig. 1). Fig. 1, it reveals that the foam expansion increased with an increase in the concentration of soy protein isolate, GMS, CMC, sugar and whipping time. Similar trends were reported by Kandasamy *et al.* (2012) for papaya, Sankat and Castaigne (2004) for banana, Bag *et al.* (2011) for bael fruit pulp.

It was observed from Fig 1 (a) that the effect of SPI, as well as GMS on foam expansion, was very high, due to protein present in the soy protein isolate and GMS. Similar results were observed for the different protein-based foaming agents (Kandasamy *et al.,* 2012; Sankat and Castaigne, 2004; Rajkumar *et al.,* 2007; Krasaekoopt and Bhatia, 2012). The combined effect of soy protein isolate, GMS and whipping time was more significant at higher levels. Similar results were also reported by Falade *et al.* (2003), Bag *et al.* (2009) and Azizpour *et al.* (2014) for various fruit pulp.

It is observed from Figure 1(b), that the foam density decreased with an increase in the concentration of soy protein isolate, GMS and CMC. The lower foam density indicated the higher whipping ability which results in more foam formation. This was due to the foaming ability of foaming agents added to the juice. The protein tends to unfold or denature during whipping, which exposes two oppositely charged ends of protein molecules such as hydrophobic and hydrophilic ends. Thus, these charged ends align themselves between air and water securing the air bubbles with their hydrophilic end directing towards the water and hydrophobic towards the air. In this way the solution entraps air and thus the foam gets stabilized by the proteins present and reducing its density.

The decrease in foam density from the original value of 0.82 to 0.61 g/cm^3 indicated the volume of air incorporated into the juice through effective whipping. Shimoyama *et al.* (2008) found similar results by using soy protein isolate concentration upto 5%, the foam density was 0.8 g/cm^3. The foam density was inversely proportional to the GMS concentration (Ismaila *et al.,* 2016). The foam density was found 0.50 to 0.71 g/cm^3 for muskmelon (Asokapandian *et al.,* 2016), 0.96 g/cm^3 to 0.54 cm^3 for mango (Rajkumar *et al.,* 2007).

From figure 1c, it was observed that the addition of foam stabilizer plays a significant role in the stability of the foam. Foam stability represents the capacity of the foam to retain the water and a way to assess how quickly the fluid flows (Kampf *et al*., 2003). The durable structure of the foam was dried rapidly and the drying substance was easily extracted from the tray. If foam breaks or declines, the drying period was increased and the consistency of foam was reduced. The stability/drainage volume of foam was influenced by the thickness of the interface, foam size distribution, interface permeability, and surface tension. The methylcellulose concentration affected the foam stability of the foamed mandarin juice. These results are comparable with Brygidyr *et al*. (1977) for tomato puree and Labelle (1966) for orange juice. It was also observed that at higher whipping time, the foam stability was decreased due to rupturing of foam bubbles and releasing of liquid phase intact in foam bubbles. DeVries (1958) and Prins (1988) mentioned in this sense that foam was more robust at high viscosity, which easily avoid the breaking of interface walls.

The result for foam expansion, density and stability was analysed by stepwise regression analysis method and shown in Table 1. The quadratic model is better suited to the experimental results and for linear, quadratic and interaction conditions the model was significant for the determination of foaming properties. The R^2 value was determined by the least square methodology and was 0.946 that indicating the model was well fitted to the results.

From Table 1, it shows that the linear terms (A, B, C, D and E), interaction terms (AB, AE, BC, BD, BE, CD and DE) and quadratic terms (A^2, B^2, C^2, D^2 and E^2) are significant model terms ($P < 0.01$). whereas the effect of the interactive terms (AC and AD) was found non-significant on foam expansion. The linear terms (A, B, C and E), interaction terms (AC, AD, AE, BD, BE, CD, CE and DE) and quadratic terms (A^2, B^2 and E^2) were found significant whereas the linear term CMC (D), interactive terms (AB and BC) and quadratic terms (C^2 and D^2) were found non-significant on foam density. The linear terms (A, B, D, E), interaction terms (AC, AD, BC and BE) are

significant model terms whereas other linear, interactive and quadratic terms found non-significant effects on foam stability.

Table 2 ANOVA of foam expansion, density and stability

Source	df	Foam expansion (%)		Foam density (g/cc)		Foam stability (%)	
		SS	F-value	SS	F-value	SS	F-value
Model	20	519.3	66.37***	0.0501	72.380**	501.20	8.00**
A-Soy Protein Isolate, %	1	6	15.34**	0.0006	16.310**	4.47	1.43NS
B-Sugar content, %	1	6.12	15.64**	0.0006	16.620**	7.40	2.36NS
C-GMS powder, %	1	39.9	101.98***	0.0052	150.480**	49.10	15.67**
D-CMC powder, %	1	7.64	19.53**	0.0001	0.012NS	200.00	63.83***
E-Whipping time, min	1	220.5	563.61***	0.0157	451.920**	0.0251	0.0080NS
AB	1	4.28	10.95*	0.0001	0.991NS	13.84	4.42*
AC	1	0.908	2.32NS	0.0002	6.480*	1.98	0.6322 NS
AD	1	1.29	3.3NS	0.0003	8.400*	25.90	8.27*
AE	1	10.22	26.13**	0.0024	68.630**	24.67	7.87*
BC	1	6.16	15.74**	0.0001	2.400 NS	6.57	2.10 NS
BD	1	37.03	94.65***	0.0064	183.380**	3.34	1.07 NS
BE	1	6.44	16.46**	0.0003	9.820*	29.89	9.54*
CD	1	29.11	74.4***	0.0021	61.90**	51.49	16.43**
CE	1	13.16	33.63***	0.0014	40.130**	0.5168	0.1649 NS
DE	1	0.13	0.3324NS	0.0006	18.580**	0.0128	0.0041 NS
A^2	1	14.71	37.59***	0.0016	46.010**	1.21	0.3860 NS
B^2	1	9.2	23.5**	0.0007	20.570*	13.78	4.40*
C^2	1	5.07	12.97**	0.0001	1.970*	45.60	14.55**
D^2	1	2.58	6.59*	7.93E-06	0.229 NS	64.65	20.63**
E^2	1	64.03	163.68***	0.0088	253.660**	0.0059	0.0019 NS
Residual	7	2.74		0.0002		21.93	
Lack of Fit	1	0.1311	0.3018NS	1.76E-08	0.0004NS	1.44	0.4202 NS
Pure Error	6	2.61		0.0002		20.50	
Cor Total	27	522.04		0.0504		523.13	
Std. Dev.		0.683		0.006		1.470	

C.V. %	2.270	0.869	1.670
R^2	0.991	0.995	0.947
Adjusted R^2	0.976	0.981	0.889
Predicted R^2	0.863	0.993	0.756

SS is sum of square, *** Significant at 0.1% Level, ** Significant at 1% Level, * Significant at 0.5% Level and NS – Non-significant

The regression equation which describes the impact of process variables on foam expansion, foam density and foam stability in terms of variable coded and actual values are shown in the following equation

Foam expansion (%) = 31.350 + 1.210A + 0.754B + 2.430C + 1.100D + 5.510E + 0.975AB – 1.970AE + 1.600 BC + 3.600BD – 0.940BE + 2.940CD – 1.820CE + $0.818A^2 – 0.653B^2 – 0.347D^2 – 1.720E^2$ ($R^2 = 0.863$) (9)

Foam density (kg/cm^3) = 0.669 – 0.007A – 0.010B – 0.030C – 0.049E + 0.009AC – 0.013AD + 0.024AE – 0.045BD + 0.011BE – 0.024CD + 0.024CE – 0.015DE – $0.009A^2 + 0.006B^2 – 0.020E^2$ ($R^2 = 0.8853$) (10)

Foam stability (%) = 85.810 + 0.770A – 0.910B + 2.970D + 1.380E + 2.180AC – 1.560AD + 2.510BC + 1.730BE ($R^2 = 0.7555$) (11)

Replacing A, B, C, D, and E with (Sp-4)/2, (Su-10)/5, (Gm –3.5)/1.5, (Cm –2)/1 and (Wt –6)/3, respectively in Eqn. (9 to11), the foam expansion, density and stability in real terms of soy protein isolate, sugar, GMS, CMC and whipping time are given in the following Eqn.

Foam expansion (%) = 17.682 – 0.038Sp – 1.529Su – 0.502Gm – 1.584Cm + 7.485Wt + 0.097SpSu – 0.328SpWt + 0.214SuGm + 0.720SuCm – 0.063SuWt +1.963GmCm – 0.405GmWt + $0.205Sp^2 – 0.026Su^2 – 0.216Gm^2 – 0.347Cm^2 – 0.191Wt^2$ ($R^2 = 0.991$) (12)

Foam density (kg/cm^3) = 0.687 – 0.0142Sp + 0.0147Su– 0.039Gm + 0.126Wt + 0.006SpGm + 0.002SpCm + 0.0002SpWt – 0.007SuCm – 0.001SuWt – 0.005GmCm + 7.76×10^{-5} GmWt – 0.010 CmWt– $0.002Sp^2 + 0.0002Su^2 + 0.002Wt^2$ ($R^2 = 0.993$) (13)

Foam stability (%) = 56.880 + 1.640Sp – 1.170Su + 18.700Cm + 0.110Wt – 0.070SpGm – 1.010SpCm + 0.290SuGm + 0.040SuWt ($R^2 = 0.9465$) (14)

The most prominent factor which affects foam expansion was found whipping time followed by GMS, soy protein isolate, CMC and sugar content. The quadratic terms soy protein isolate, sugar, CMC and whipping time were also significant, indicating nonlinear variation in foam expansion due to change in protein isolate and whipping time. The interaction terms were significant which indicates the influence of the combined effect on foam expansion. The most prominent factor which affects foam density was found in whipping time followed by GMS, sugar content and soy protein isolate. The presence of negative interaction terms indicates the decreased foam density. All the coefficients of foam density were decreased with an increase in coefficients of foam expansion. The CMC is the most predominant factor which affects the foam stability followed by whipping time, sugar content and soy protein isolate. The sugar content increases with a decrease

in foam stability. The presence of positive interaction terms between soy protein isolate and GMS, SPI and CMC, sugar content and GMS, sugar content and whipping time were significant on foam stability.

Numerical optimization (CCD) was performed over the foaming parameters to obtain the optimum condition for the drying process in design expert software version 11.0. Graphical multi-response optimization technique was adopted to determine the workable optimum conditions for the foamed Nagpur mandarin juice concentrate. The optimum conditions for SPI 2.10%, sugar 5.10%, GMS 2.75%, CMC 1.75% and whipping time 8 min corresponding to these values of foam expansion was 36.25%, foam density 0. 65 g/cc, foam stability 84.03%.

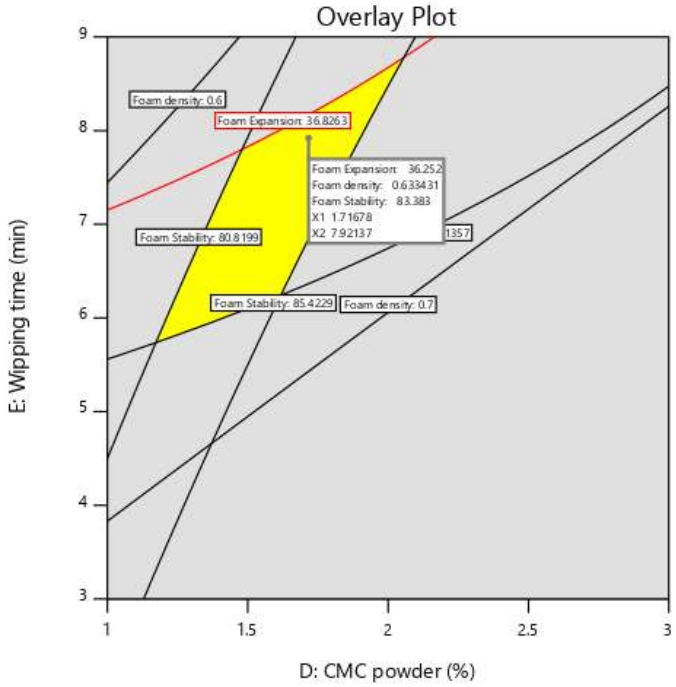

Fig. 2 Superimposed contour plots for optimization of foaming agents in Nagpur mandarin juice

Drying characteristics of foamed Nagpur mandarin juice drying

The foam was prepared with optimum conditions for SPI (2.10%), sugar (5.10%), GMS (2.75%), CMC (1.75%) and whipping time (8 min) used for the drying study. The initial moisture content of the foamed juice was in the range of 411.51 to 398.50% (db) for all investigated samples and after drying up to constant bone-dry weight, the moisture content was reduced in the range of 4.77 to 1.39% (db). The variation in drying time was found in between 18 to 58 min for 180 to 900 W microwave power at 2 to 6 mm drying bed thickness (Fig 3a). It was observed that the drying time decreased with an increase in microwave power as well as reduced in drying bed thickness. The effect of microwave power is more as compared to drying bed thickness from 2 to 6 mm. Similar types of results have been reported by various researcher viz. Darvishi et al. (2014) for pepper, Rajkumar et al. (2007) for Alfanso Mango, Alibas (2014) for celery leaves.

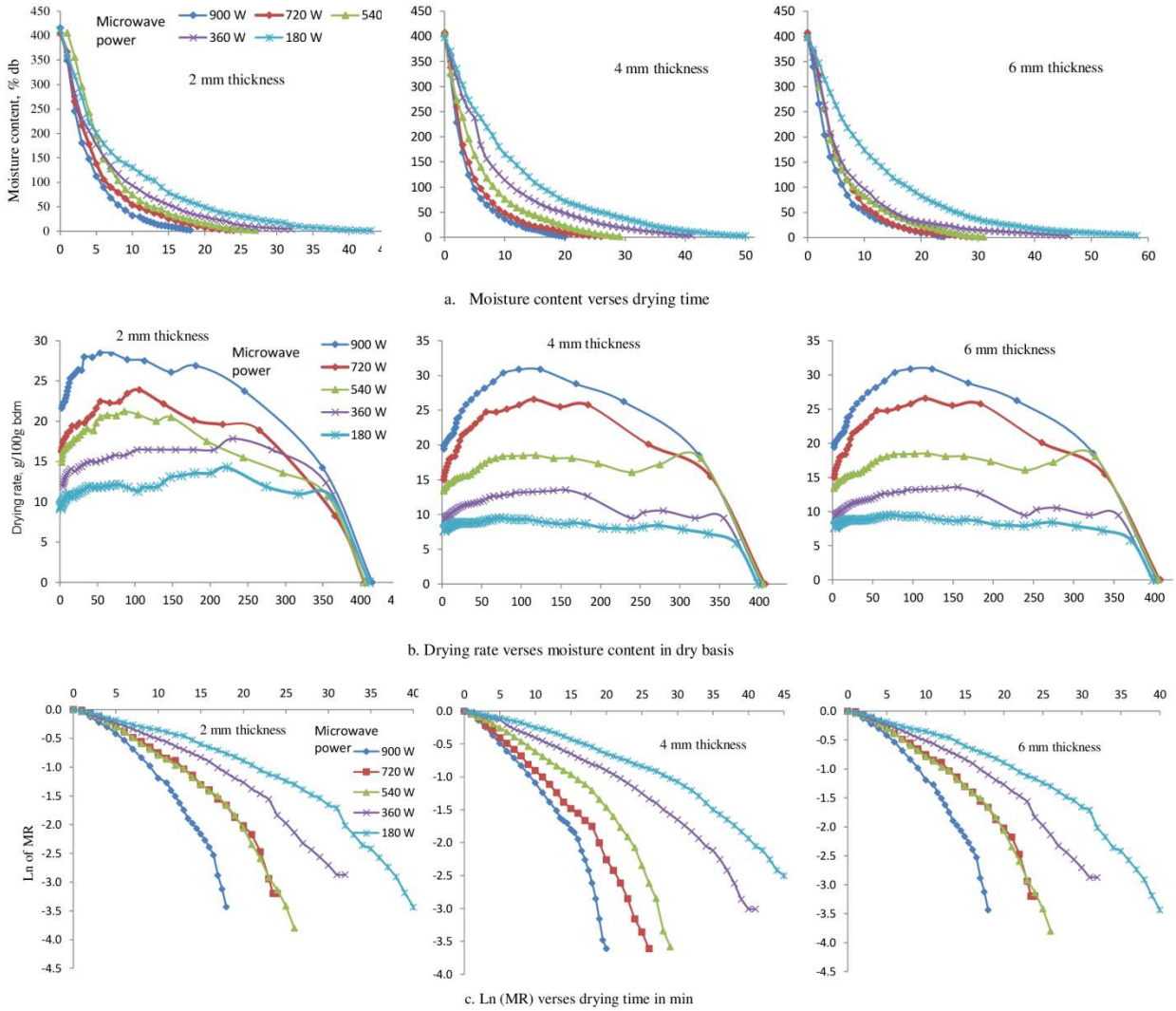

Fig 3 Effect of a) moisture content vs drying time b) drying rate vs moisture content c) Ln (MR) vs drying time at varying microwave power and drying bed thickness

Fig. 3b shows that the drying rates were more after an initial short period of the process probably due to evaporation and moisture from the surface of the mandarin juice layer and later decreased with decreasing moisture content, for all the drying conditions once the drying process was governed by moisture diffusion. Further, it was observed from the figures that no constant rate period was found, the entire drying took place in falling rate period during drying of foamed juice. Similar results were reported by Shukla *et al.* (2014) for green peas, Akpinar and Bicer, (2004) for vegetables. Chayjan and Kaveh (2016) reported that the drying rate increased at the beginning of the process due to sample heating. After an initial short period, the drying rate reached a maximum value and then it followed falling rate in all drying conditions.

In order to investigate the effects of the moisture content on D_{eff} and to evaluate the activation energy for varying microwave power during drying, an evaluation of the falling rate was conducted to assess D_{eff}. The ln (MR) was graphed against average drying time (t) with varying microwave

power in Fig 3c. It was presented that the relationship was of a non-linear behavior with all drying process. The effects of the moisture content on D_{eff} in order to determine the activation energy for varying microwave power was evaluated to the analysis of the reduced rate period. Ln (MR) was compared to the average drying time for various microwave power.

This non-linearity relationship might be due to reasons like shrinkage in the product, variation in moisture diffusivity with moisture content and change in product temperature during drying (Franco et al. 2015). The D_{eff} of foamed Nagpur mandarin juice was calculated using a different power of Microwave at different drying bed thicknesses. This shows that, as the moisture content falls, the vapor permit increases if the capillaries are visible. This increases the pressure of the water vapor within capillaries and causes the opening of capillaries due to the pressure.

The natural logarithms of moisture ratio (ln MR) were plotted against average drying time (t) for different microwave power. This non-linearity in the relationship might be due to reasons like shrinkage in the product, variation in moisture diffusivity with moisture content and change in product temperature during drying. Similar findings were observed by Hawlader *et al. (*1991) and Kannan and Bandopadhyay, (1995). The non-linearity of the curves, indicative of the variation in moisture diffusivity with moisture content, was used to estimate effective moisture diffusivity of foamed Nagpur mandarin juice, under different drying conditions. This indicates that as moisture content decreased, the permeability to vapor increased provided the pore structure remained open. The temperature of the product rises rapidly in the initial stages of drying, due to more absorption of microwave heat, as the product has a high loss factor at higher moisture content. A similar trend in the variation in the moisture diffusivity with moisture content was reported by Sharma and Prasad (2004), Sharma *et al.* (2005), Workneh *et al.* (2011) and Prabhanjan*et al.* (1995).

The average actual effective moisture diffusivity $(D_{eff})_{avg}$ values of foamed Nagpur mandarin juice using foaming agents dried at different microwave power varied considerably with moisture content and microwave power from 0.993 x 10^{-9} to 3.367 x 10^{-9}, 1.623 x $10^{-9}$to 10.009 x 10^{-9} and 1.826 x 10^{-9} to 14.605 x $10^{-9}$$m^2/s$ for 2, 4 and 6 mm drying bed thickness and predicted moisture diffusivity was found in the range of 0.101 x 10^{-9} to 6.179 x 10^{-9}, 1.566 x $10^{-9}$to 9.940 x 10^{-9} and 5.327 x 10^{-9} to 13.700 x $10^{-9}$$m^2/s$ for 2, 4 and 6 mm drying bed thickness, respectively (Table 2), which lies within the general range of 10^{-12} to 10^{-8} m^2/s for drying of food materials (Doymaz, 2010). Similarly, the effective moisture diffusivities (D_{eff}) ranged from 1.57×10^{-8} to 2.61×10^{-8} m^2/s for carrot pomace (Abano *et al.,* 2019). It was observed from Table 2, that the moisture diffusivity values increased with both parameters i.e. microwave power and drying bed thickness.

The activation energy was calculated by plotting ln(D_{eff}) vs the reciprocal of the microwave power (1/P) and a straight line with a negative slope was obtained which implies that the diffusivity of the samples decreases linearly with an increase in (1/P) during microwave drying. The value of activation energy shows the sensitivity of the diffusivity against microwave power. From Table 3, the activation energy was found varied from 19.54 to 17.48 W/g with an increase in drying bed thickness from 2 to 6 mm.

Table 3 Activation energy for microwave drying of foamed juice

Sr. No	Drying bed thickness, mm	Slope of Arrhenius plot	R, kJ /kg mol K	Activation energy, W/g
1	2	-260.69	8.31	19.54
2	4	-419.52	8.31	18.11
3	6	-466.50	8.31	17.48

These values are closed to the E_a values reported by various researchers viz.12 to 32.82 W/g for Trabzon persimmon (Celen, 2019), 13.52 and 14.20 W/g for celery leaves (Alibas, 2014).

Conclusions:

Nagpur mandarin powder was produced by foam mat drying using an optimum foaming condition for soy protein isolate 2.10%, sugar content 5.10%, glycerol monostearate 2.75%, carboxymethylcellulose 1.75% and whipping time 8 min corresponding to foam expansion was 36.25%, foam density 0. 65 g/cc, foam stability 84.03%. The drying time decreased with an increase in microwave power as well as reduced in drying bed thickness. The drying time was found 18 to 58 min at 180 to 900W microwave power and 2 to 6 mm drying bed thickness. The D_{eff} increases with an increase in microwave power and drying bed thickness of foamed Nagpur mandarin juice.

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Conflict of interest

They have no conflict of interest.

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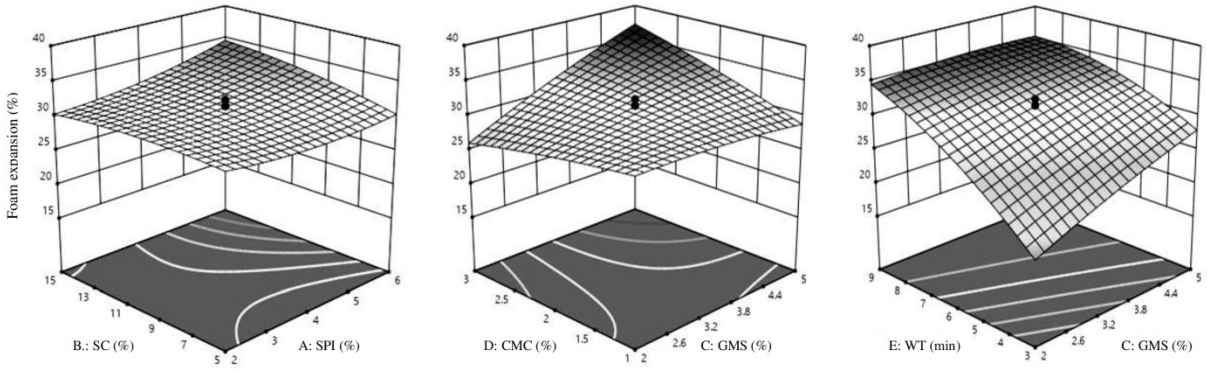

a. Foam expansion

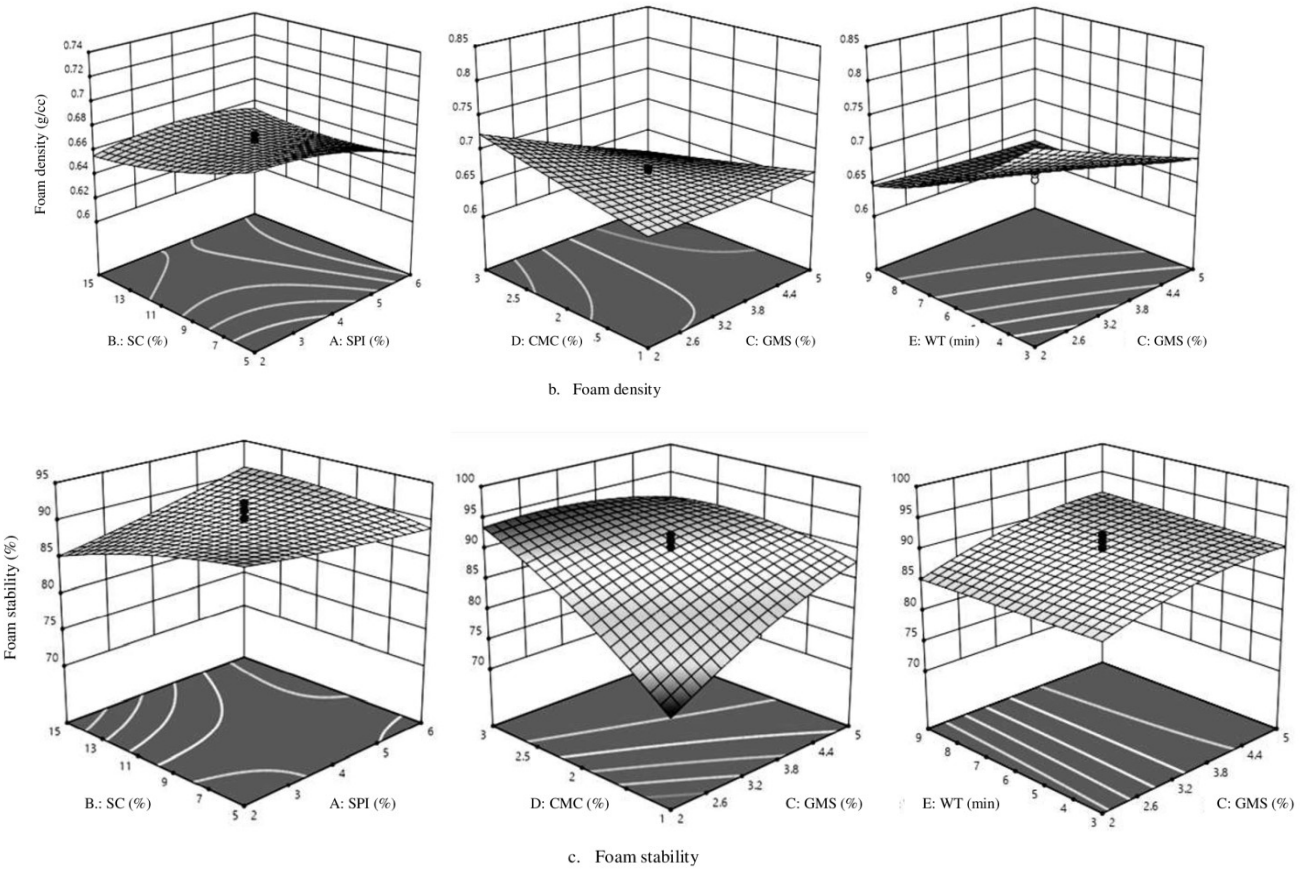

Fig. 1 The contour and response surface showing the effect of foaming agents, stabilizer, sugar content and whipping time during foaming of Nagpur mandarin juice on **a**. Foam expansion **b**. foam density and **c.** foam stability.

Table 2. Moisture diffusivity in microwave drying of foamed juice

S. N.	MP, W	DT, mm	Diffusivity equation	Actual Diffusivity, (D_{eff}) x10^9,m^2/s	Predicted Diffusivity, (D_{eff}) x 10^{-9},m^2/s	R^2
1	180	2	$y = -0.0023x^2 + 0.015x - 0.191$	0.933	2.195	0.991
2	360	2	$y = -0.0023x^2 - 0.017x - 0.064$	0.933	0.101	0.996
3	540	2	$y = -0.0046x^2 - 0.007x - 0.900$	1.866	1.992	0.992
4	720	2	$y = -0.0059x^2 - 0.0005x - 0.115$	2.394	4.085	0.993
5	900	2	$y = -0.0083x^2 - 0.0226x - 0.059$	3.367	6.179	0.992
6	180	4	$y = -0.0013x^2 + 0.004x - 0.113$	1.623	1.566	0.994

7	360	4	$y = -0.0014x^2 - 0.014x - 0.071$	2.272	3.659	0.994
8	540	4	$y = -0.004x^2 + 0.0082x - 0.160$	6.491	5.753	0.983
9	720	4	$Y = 0.0035x^2 - 0.0417x - 0.065$	7.303	7.846	0.995
10	900	4	$y = -0.0074x^2 - 0.0085x - 0.153$	12.009	9.940	0.978
11	180	6	$y = -0.0005x^2 - 0.022x + 0.037$	1.826	5.327	0.998
12	360	6	$y = -0.0002x^2 - 0.055x + 0.039$	7.303	7.420	0.995
13	540	6	$y = -0.0039x^2 + 0.014x - 0.180$	10.954	9.514	0.982
14	720	6	$y = -0.0032x^2 - 0.038x + 0.002$	12.414	11.607	0.993
15	900	6	$y = -0.0047x^2 - 0.0185x - 0.103$	14.605	13.700	0.978