CHAPTER 6

OBJECTIVE 4

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DEVELOPMENT AND CHATERIZATION OF FOAM MAT TAMARILLO POWDER

4.1 Introduction

Tamarillo is a perishable fruit, and the pulp is subjected to convective drying and spray drying techniques [21] for preservation and use. Literature reports mention the use of spray drying techniques for tamarillo [3, 38]. However, spray drying technique has limited suitability for pulp and viscous juices [16]. The main disadvantages of connective drying are consumption of drying time, degradation of bioactive compounds, and loss of end product quality characteristics [29]. Although, foam mat drying is an old technique, it is still being used by researchers due to its various advantages over traditional drying [8]. In comparison to freeze and spray drying processes, product quality obtained by foam mat drying is relatively low but lower processing cost and ease in drying process makes the technique more utilizable. Heat sensitive liquids or purees are transformed into stable foam using foaming agents and stabilisers and distributed in a thin layer for dehydration at a low temperature. Foaming agents create large surface area for moisture diffusion, lowers the surface tension between the gaseous and liquid phase, and increases foam porosity, because of which the drying process is faster [8, 30]. Besides reducing the drying time, foaming agents have the ability to significantly control the physicochemical properties of powder in terms of expansion, porosity, and stability, allowing for the achievement of desired physicochemical quality attributes such as, instant water solubility, good flowability, and acceptable colour. Different foaming agents are used for the development of foams. Egg albumin and gelatin were used for the preparation of beetroot powder [35], soy protein for obtaining muskmelon powder [4], and whey protein for banana foam mat drying [46]. The most important functional properties possessed by foaming agents are emulsification, gelation, water binding, viscosity, and whipping properties that play crucial roles in the processing of foam mat powders [4].

Researchers have studied the powder characteristics of foam mat dried foods, such as cocoa powder [8], *Syzygium cumini (L.)* [15], blackcurrant pulp [51]; tamarind [49]; bacaba [16]; cassava [6] and many other fruits and vegetables. Foam mat dried powders show good hygroscopicity, water activity, and good colour properties [35]. Foam mat dried powder is a good source of phenolic compounds, flavonoids, and anthocyanins [14, 15].

Tamarillo, being a nutritionally and phytochemically rich fruit, has very high potential to be utilized in food systems as a functional ingredient when incorporated in the dried form. Till now, to the best of our knowledge there is no scientific report available on the foam mat dried tamarillo powder. Therefore, this study was done to evaluate the effect of different foaming agents and their concentrations on blanched tamarillo puree and evaluate the powder characteristics, drying kinetics, moisture diffusivity, and retention of bioactive compounds.

6.2. Materials and Methods

6.2.1. Materials

Red tamarillo was purchased from the local market in Kohima, Nagaland. Fruits were packed in plastic ziplock pouches and kept at -20º C until further analysis. Whey protein concentrate (WPC) and soy protein concentrate (SPC) were procured form Health Kart, India; gelatin (GEL) was purchased from SRL, India; and eggs (ALB) were purchased from the local market adjacent to Tezpur University.

6.2.2. Sample and foam preparation

Tamarillo was blanched in boiling water for 90 s. The peel and seeds were separated from the blanched fruit, and the pulp was processed into puree using mixer grinder (Philips HL 1632, India). The foam was prepared according to Ng and Sulaiman [35] with some modifications. The known amount of foaming agent (5% and 10%) was added into the pre-weighed puree and whipped with a kitchen whipper for 10 min (Philips, HR3705/10). The foams were dried and converted into powder and were kept in an airtight plastic container at -20^{o}C until further analysis. The foaming agents used were WPC, SPC, ALB, and GEL and their foams were coded as WPC-5F and WPC-10F, SPC-5F and SPC-10F, ALB-5F and ALB-10F, and GEL-5F and GEL-10F, respectively to indicate concentration levels of 5 and 10%. The dried foams were coded WPC-5P and WPC-10P, SPC-5P and SPC-10P, ALB-5P

and ALB-10P, and GEL-5P and GEL-10P. Control-F and Control-P represent the raw tamarillo pulp without any foaming agent before and after drying, respectively.

The foams were immediately analysed for foam density and foam expansion [35]. Foam expansion was determined from the volume of initial puree taken and the volume of final foam developed (Eq.1). A fixed volume of pulp or foam was taken in a graduated cylinder and weighed to get the density (Eq.2). The foam stability index (%) is the difference between the initial foam volume and the final foam volume after 300 min, according to Eq. 3 [33].

$$Foam\ Expansion = \frac{x_1 - x_0}{x_0} \quad (1)$$

$$Foam\ density = \frac{weight\ of\ foam\ (g)}{Volume\ of\ foam\ (ml)} \quad (2)$$

Here, x_0 and x_1, are the initial and final volume of the foam, respectively

$$Foam_{stability} = \frac{V_{foam}}{V_o} \times 100 \quad (3)$$

Here, V_o is the initial volume, V_{foam} is the volume after 30 min.

6.2.3. Selection of drying temperature and drying kinetics

For selection of specific drying temperature, initial drying was carried out at three temperatures (50, 60 and 70°C). Based upon on the maximum content of phenolics and total carotenoids retained in the powder at the end of drying, 50°C temperature was selected for drying of the foams.

The prepared foam was poured on pre-weighed drying trays in 3 mm thick layer and dried in a laboratory tray drier (Labotech, BDI-51, B. D. Instrumentation, India) at 50ºC. The weight of the trays was taken after a known interval of time. The weight of the dried foams was measured in triplicates until constant weight. Five different semi-theoretical models for drying kinetics, namely Page, Lewis, Handerson-Pabis, Lograthimic, and Avhad and Marchetti were employed. The mathematical expression of the models is given in Table

6.1. The goodness of fit was considered with high R^2 (coefficient of determination) value and low RMSE (root mean square error) [7].

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

In Eq. 4, MR stands for moisture ratio, M_t stands for moisture content at any time, M_e stands for equilibrium moisture content, M_o stands for initial moisture content (kg water/kg dry matter)

As M_e (equilibrium moisture content) is very low in comparison to M_t (moisture content at any time) and M_o (initial moisture content), Me can be neglected in Eq. (4) and simplified as in Eq. 5.

$$MR = \frac{M_t}{M_o} \quad (5)$$

Table 6.1. Different drying models with their equation expressions

Sl no	Name of Model	Model Equation	Parameters description	References
1	Lewis Model	MR= exp(−kt)	k = constant	[26]
2	Henderson and Pabis	MR = a exp (−kt)	a, k =constant	[5]
3	Logarithmic	MR= a exp (-kt) +c	a, k =constant	[26]
4	Page	MR=exp $(-k\,t^n)$	k, n = constant.	[5]
5	Avhad and Marchetti	MR=a*exp$(-k\,t^n)$	a, k, n = constant	[5]

6.2.3.1. Moisture diffusivity

Moisture diffusivity of the tamarillo foam was calculated according to Fick's second law of diffusion that is applied for an infinite flat plate (Eq.6). Fick's second law of diffusion is applied widely on food samples and helps to determine the falling rate period in the drying process [47].

$$MR = \frac{8}{\pi^2} \exp\left(-\frac{\pi^2 D_{eff}\, t}{4\, L^2}\right) \quad (6)$$

Where, D_{eff} stands for effective moisture diffusivity (m^2/s), L stands for thickness layer (m). Effective moisture diffusivity (D_{eff}) was calculated by plotting ln (MR) versus drying time from the experimental data. The plot in the graph was found to be a straight line with a negative slope, and 'K' is related to D_{eff} using Eq. 7.

$$K = \frac{\pi^2 D_{eff}}{4\, L^2} \quad (7)$$

6.2.4. Powder analysis

6.2.4.1. Bulk density, tapped density, flowability, and cohesiveness

The procedures of Santhalakshmy et al. [41] with some modifications were followed to measure these properties of the foam mat dried powders. For bulk density, precisely weighed 4 g of sample was taken in a 10 mL volumetric cylinder and its volume was noted. For tapped density, the volumetric cylinder with sample was tapped on a surface for equal times and volume was recorded. Flowability (Carr index) and cohesiveness (Hausner ratio) were calculated using the bulk density and tapped density values as given in Eq. 8 and Eq. 9 respectively (Table 6.2 and 6.3).

$$Flowability = \frac{Tapped\ density - Bulk\ desnity}{Tapped\ density} \times 100 \quad (8)$$

$$Cohesiveness = \frac{Tapped\ density}{Bulk\ density} \quad (9)$$

Table 6.2. Classification for flowability in terms of Carr Index [41]

Carr Index (CI) %	Flowability
< 15	Very good
15-20	Good
20-35	Fair
35-45	Bad
> 45	Very bad

Table 6.3. Classification for cohesiveness in terms of Hausner ratio [41]

Hausner ratio (HR)	Cohesiveness
< 1.2	Low
1.2-1.4	Intermediate
> 1.4	High

6.2.4.2. Wettability and Solubility

The wettability and solubility of foam mat dried samples were determined according to Santhalakshmy et al. [41]. Wettability was calculated using the time required for complete submersion of 1 g of powder samples in 400 mL of distill water taken in a beaker. The solubility (%) was calculated by taking 1g of powder samples and dispersing it into 100 mL of distilled water using mixer blender for 2 min. The mixture was centrifuged at 3000 x g for 5 min. A 25 mL of liquid aliquot was transferred into pre-weighed Petri dish and oven dried at 105^{o}C for 4 h. The difference in weight was used for the calculation of solubility.

6.2.4.3. Hygroscopicity

To determine hygroscopicity, 1 g of powder sample was placed in a closed container filled with saturated NaCl solution at 25ºC and 75.29% RH [20]. The container was stored for 7 days and change in weight was noted. Hygroscopicity of the sample was calculated and expressed as grams of absorbed moisture per 100 g of dry matter.

6.2.4.4. Colour parameters

The L* (dark/lightness), a* (green/red) and b*(blue/yellow) values of powder samples were obtained using Hunter colorimeter. Further, chroma (intensity of colour) and hue angle (colour perception) of samples were determined by Eq. 10 and Eq. 11, respectively.

$$Chroma = \sqrt{(a^*)^2 + (b^*)^2} \quad (10)$$

$$Hue\ angle = tan^{-1}\frac{b^*}{a^*} \quad (11)$$

6.2.5. Scanning electron microscopy

The microstructure of foam dried powder samples were obtained using scanning electron microscope (Jeol, JSM-6390LV, Jeol Ltd., Japan). Prior to analysis, powder samples were coated on SEM stubs with double-sided tape using auto fine coater (Jeol JFC1600) and images of x 2500 magnification were captured.

6.2.6.1. Determination of phytochemicals in foam mat dried powder

6.2.6.1.1. Total phenolic content

The total phenolic content (TPC) in tamarillo was determined according to Saikia et al. [40]. For the analysis, an aliquot of 0.5 mL of diluted sample extracts was taken in test tubes and mixed with 2.5 mL of Folin-Ciocalteu reagent (diluted 1:10). For blank, sample extract was replaced with distilled water. After 5 min of incubation, 2 mL of sodium carbonate (7.5%) was added into each test tube, vortexed and kept for 2 h in a dark place at room temperature. Absorbance was read by UV-Vis spectrophotometer (Thermo-Fischer Evolution A600) after incubation time against the reagent blank mixture. Gallic acid was used as standard, and results are expressed in mg GAE/100g.

6.2.6.1.2. Total flavonoid content

The total flavonoid content (TFC) in tamarillo samples was determined according to Saikia et al. [40]. For the analysis, an aliquot of 0.5 mL of sample was mixed followed by addition of 1.5 mL of ethanol (95%), 0.1 mL of aluminium trichloride (10%), 0.1 of potassium acetate (1M), and 2.8 mL of deionized water. The test tube was vortexed and kept for 2 h in a dark place at room temperature for 40 min. The absorbance of the sample was read at 415 nm in UV-Vis spectrophotometer (Thermo-Fischer Evolution A600) against blank. Quercetin was used as standard, and results are expressed in mg QE/100g.

6.2.6.1.3. Total carotenoids content

The total carotenoids content in the tamarillo sample was calculated according to the method adopted by Rodriguez-Amaya et al., [39] with some modifications. Briefly, 1g of juice sample was mixed into 10 mL of hexane:acetone:ethanol (2:1:1 v/v/v) and centrifuged at 7000 x g for 10 min. The upper layer of mixture was separated carefully and adjusted to

10 mL using hexane. The absorbance of hexane containing carotenoids was read at 450 nm (Thermo-Fischer Evolution A600) and results was reported as mg of β-carotene equivalents (mg β-CE)/ g of sample.

6.2.7.2. DPPH scavenging activity and ABTS radical scavenging activity of foam mat dried powder

6.2.7.2.1. DPPH radical scavenging activity

DPPH radical scavenging activity of tamarillos was calculated according to to Saikia et al. [40] with some modification. In a test tube, 200 µL of sample extract was taken followed by the addition of 2.8 mL of DPPH radical prepared in methanol, vortexed and kept for 30 min in a dark place for incubation. The absorbance of sample was read at 517 nm using UV-Vis spectrophotometer (Thermo-Fischer Evolution A600) against blank (Eq. 12).

$$DPPH\ activity\ (\%) = \frac{A_o - A_s}{A_o} \times 100 \quad (12)$$

here A_o is absorbance of control blank, and A_s is sample absorbance

6.2.7.2.2 ABTS radical scavenging activity

ABTS radical scavenging activity of tamarillo samples was calculated following the method of Marboh and Mahanta [32]. For preparation of fresh solution of ABTS solution, 2.45 mM of potassium acetate and 7 mM ABTS reagent were mixed in ethanol separately. The radical solution was prepared by mixing potassium acetate and ABTS solution in (1:1 v/v) and kept for incubation for 16 h at room temperature in dark. After incubation, the radical solution was read for absorbance of 734 nm using UV-Vis spectrophotometer (Thermo-Fischer Evolution A600) against blank. The absorbance value of solution was adjusted to 0.70 ± 0.05 using ethanol as diluent. In a test tube, 0.3 mL of sample extract was taken and 2.7 mL of ABTS solution was mixed. The radical scavenging activity was calculated using recorded absorbance of sample (Eq. 13).

$$ABTS\ activity\ (\%) = \left(\frac{A_o - A_s}{A_o}\right) \times 100 \quad (13)$$

Here, A_o and A_s stands for absorbance for control and sample values, respectively

6.2.8. HPLC analysis of phenolic acids of foam mat dried powder

The phenolic acids of developed foam mat dried powder were identified and quantified using standards by UHPLC (Ultimate 3000, Thermo Scientific, USA). The identification of the phenolic acids present in the sample was done in reverse phase HPLC using C18 column with diode array detector. The sample extract was filtered through 0.45µm syringe filter prior to the injection. The gradient mode consisted of two solvents, A (0.1 % formic acid) and B (100 % acetonitrile) at 35°C. The flow rate of the solvent was kept at 0.5 mL/min at 330 nm wavelength and the gradient flow pattern was 15%B for 5 min, 20–35% B for 10 min, 35–50% B for 10 min, 50–60% B for 5 min, and 60% B for 5 min [19].

6.2.9. HPLC of carotenoids of foam mat dried powder

The carotenoids in the foam mat tamarillo powder were identified and quantified using UHPLC (Utimate 3000, Thermo Scientific, USA) with the help of internal standards in reverse phase in C30 column using diode array detector. A calibration curve was developed. The sample extract of the foam mat dried powder was filtered through 0.45 µm syringe filter prior to injection. A gradient mode consisting of two solvents, A (methanol/acetonitrile/water 84:14:4, v/v/v) and (B (dichloromethane) at 25ºC was used. The flow rate of the solvent was kept at 1 mL/min at a wavelength of 450 nm using gradient flow rate with 100% A and 0% B initially, raised to 10% B at 4 min, 18% B at 12 min, 21% B at 17 min, 30% B at 20 min and maintained until 25 min, increased further to 39% B at 28 min, 60% B at 40 min and returned to re-equilibration with initial solvent parameters [25].

6.2.10. Statistical analysis

Analysis of variance (ANOVA) was applied for the analysis of results using Duncan multiple range test (DMRT) at 95% significance level ($p < 0.05$) using statistical software (SPSS 24.0, IBM Corporation, Armonk, NY). All the results reported are expressed in mean ± standard deviation of triplicate readings.

6.3. Results and Discussion

6.3.1. Selection of drying temperature

Drying was carried out at 50, 60 and 70°C, and drying temperature showed significant difference on the phenolic content of the tamarillo powder. Retention decreased with increase in temperature (Table 6.4). The degradation of the phenolic content of fruits is directly related to the drying temperature [13] that may cause changes in chemical structure, and favour formation of degradation products or binding of phenolic compounds with proteins [7], which ultimately lead to lower extraction yield.

The highest retention of carotenoids was found at 50°C (1.82 mg βCE/g) and lowest at 70°C with 1.47 mg βCE/g of carotenoids. pH, heat, oxygen and temperature are the factors that degrade carotenoids [23]. Song et al. [45] studied the effect of drying temperture on carotenoids in pollens and observed greater degradation at 60°C and 70°C than at 50°C. As maximum retention of phytochemical compounds was observed at 50°C, foam mat drying was carried out at 50°C.

Table 6.4. Phenolic and total carotenoids found in tamarillo powder at different temperatures

Drying temperature (°C)	**TPC (mg GAE/g)**	**Total carotenoids content (mg βCE/g)**
50	433.91 ± 0.98^{a}	01.82 ± 0.03^{a}
60	425.36 ± 0.24^{b}	01.63 ± 0.02^{b}
70	423.29 ± 0.72^{c}	01.47 ± 0.01^{c}

Values are expressed in mean ± standard deviation, the different letter on top (a-c), indicate the significant difference between column ($P<0.05$) between means according to Duncan's multiple range test.

6.3.2. Foam properties

6.3.2.1. Foam expansion

Foam expansion ranged from 22.22-52.25% and expansion in the control sample was 08.74% (Table 6.5). A significant difference among the foaming agents and their concentration was found, with lowest expansion seen for ALB-5F and highest expansion in WPC-10F. The increased expansion at 10% concentration implied that the protein solubility was not hindered by the increased amount of protein in the foam [10]. Foaming capacity

correlates with the rate of change of surface tension. Our results show that whey proteins are better surface tension depressors among the different proteins studied. This may be attributed to the easy unfolding of its structure at the air-liquid interface [10].

6.3.2.2. Foam density

Foam density of the different foaming agents (Table 6.5) ranged from 0.64-0.82 g/cm^3, while control (raw tamarillo) sample density was 0.98 g/cm^3. It was noticed that addition of the foaming agents and changing their concentration showed significant impact on the density. Highest density was found ALB-5F and lowest in WPC-10F. Increase in concentration reduces the surface tension and transition from aqueous phase to aqueous-air phase [2]. Albumin showed to trap less air compared to other agents. Similar results of decrease in the foam density from 0.65 to 0.63 g/cm^3 with the increase in concentration from 1 to 3% of egg white was reported for sour cherry foam [1]. Higher foam density delays the moisture removal during drying as less surface area is exposed to the drying air [22, 35].

Table 6.5. Foam expansion and foam density of the developed foams

Sample code	Foam expansion (%)	Foam density (g/cm^3)
Control-F	08.74 ± 0.09^{h}	0.98 ± 0.02^{a}
ALB-5F	22.22 ± 0.01^{g}	0.80 ± 0.01^{b}
ALB-10F	32.23 ± 0.16^{e}	0.76 ± 0.05^{d}
WPC-5F	39.10 ± 0.01^{d}	0.77 ± 0.01^{d}
WPC-10F	52.25 ± 0.04^{a}	0.64 ± 0.01^{h}
SPC-5F	30.43 ± 0.25^{f}	0.78 ± 0.02^{c}
SPC-10F	50.31 ± 0.04^{b}	0.69 ± 0.01^{g}
GLE-5F	37.19 ± 0.07^{d}	0.72 ± 0.01^{d}
GLE-10F	49.40 ± 0.09^{c}	0.66 ± 0.04^{f}

Values are expressed in mean ± standard deviation, the different letter on top (a-g), indicate the significant difference between column ($P<0.05$) between means according to Duncan's multiple range test.

6.3.2.3. Foam stability

The stability of the prepared foams up to 300 min is presented in Fig. 6.1. The foam stability varied between 90.0% and 98.40% of the control, and stability shown by the different foams were in the order WPC-10F> WPC-5F > SPC10F > SPC-5F > GEL-10F > GEL-5F > ALB-10F >ALB-5F. Foam stability increased with concentration of the foaming agents. The increase in protein content helps to hold the structure of foam and maximize the interfacial tension, which prevents the air cells from coalescence [35]. It was observed that WPC and SPC were quite impressive in terms of stability among the foaming agents. The differences in the foam stability can be attributed to the differences in the type of amino acids present and their sequence, shape of the proteins, and charges present on the protein side chains as they determine the ability of the proteins to rapidly adsorb at the interface, unfold, and allow for interactions among the protein strands. Such a rapid reaction is required to prevent coalescence of newly formed bubbles and stabilize the bubbles due to the elastic protein film that subsequently prevents it further thinning and rupture [50]. Contrary to Lomakina and Mikova [31], the use of liquid egg white in comparison to protein concentrates exhibited inferior foam properties, such as higher density and lower stability.

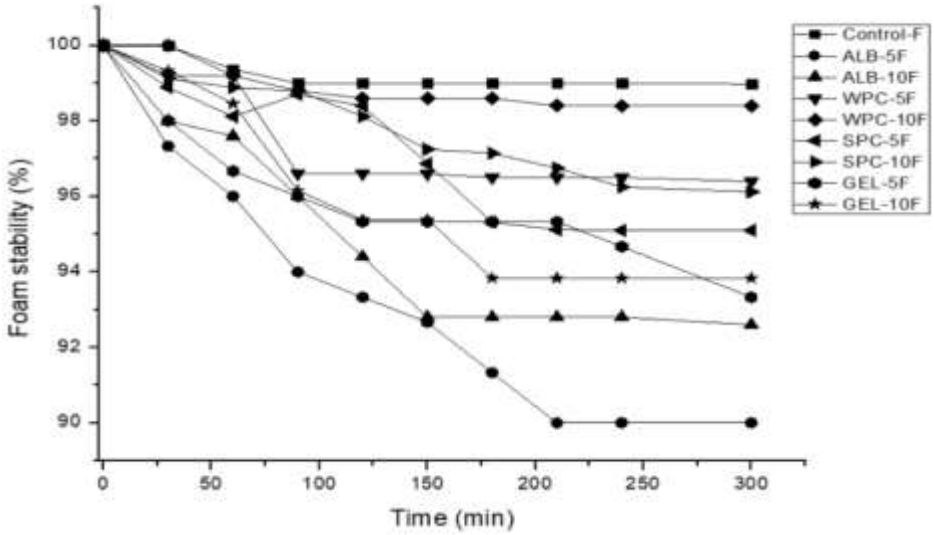


Fig. 6.1. Effect of foaming agent and concentration on foam stability

6.3.3. Drying kinetics and moisture diffusivity

It was observed that an increase in the concentration of foaming agents up to 10% helped to increase the mass transfer and enhance the drying of foam puree, as also reported by Suet Li et al. [28] . The models applied on drying kinetics were semi-theoretical in nature and the obtained non-linear regression was applied and the statistical results and coefficient are given in Table 6.6. Logarithmic model was found to be best among the models with high R^2 (0.9783-0.9922) and low RMSE values (0.0152-0.0395). Logarithmic model was also judged to give the best fit for drying of yacon foam [20].

The effective moisture diffusivity of a food material characterizes the mass transfer properties of moisture, including molecular diffusion, liquid and vapor diffusion, hydrodynamic and other mass transfer mechanisms. The moisture diffusivity of the foam mat powders was higher than the control sample and it ranged from 1.33-1.87 × 10^{-8}, with ALB-5P and ALB-10P registering the lowest and highest values, respectively (Table 6.7). The creation of air bubbles in the pulp facilitated the increased moisture removal in the foamed pulp, resulting in an increase in moisture diffusivity. Moisture diffusivity was higher at higher concentration of the foaming agents. SPC exhibited good values.

6.3.4. Powder characteristics

6.3.4.1. Bulk and tapped density of powder

The bulk density was seen to significantly differ among the foam mat dried powders (Table 6.8) Highest density was shown by SPC-5P (0.57 g/mL) and lowest by GEL-5P (0.44 g/mL), while the density of the control sample was 0.40 g/mL. The desirable values of bulk density of foam mat dried powder is between 0.2 and 0.6 g/mL [36]. Bulk density of the powder correlated with the concentration of foaming agents. Dehghannya et al. [17] observed that increase in the concentration of egg albumin from 0.2 to 0.4 decreased the bulk density of the powder from 0.40 to 0.34 g/cm^3.

The tapped density of the foam mat dried powders ranged from 0.51-0.64 g/mL, while that of the control sample was 0.54 g/mL. Tapped density decreased with the increase in concentration of foaming agent, that is in concurrence with foam-mat dried lime juice [17].

Table 6.6. Regression analysis of the drying models.

Model	Parameters	Samples								
		Control-P	**ALB-5P**	**ALB-10P**	**WPC-5P**	**WPC-10P**	**SPC-5P**	**SPC-10P**	**GEL-5P**	**GEL-10P**
Lewis	k	0.0022	0.0049	0.0071	0.0050	0.0056	0.0063	0.0066	0.0056	0.0059
	χ^2	0.0011	0.0029	0.0054	0.0013	0.0023	0.0044	0.0034	0.0018	0.0034
	SSE	0.0345	0.0406	0.1503	0.0373	0.0632	0.1226	0.0957	0.0511	0.0956
	R^2	0.9838	0.9776	0.9089	0.9788	0.9719	0.9242	0.9441	0.9719	0.9404
Henderson and Pabis	a	1.0098	0.9940	0.9190	0.9782	1.05865	0.9264	0.9401	0.9769	0.9337
	k	0.0022	0.0049	0.0063	0.0048	0.00586	0.0057	0.0060	0.0055	0.0053
	χ^2	0.0012	0.0015	0.0047	0.0013	0.0019	0.0038	0.0031	0.0018	0.0029
	SSE	0.0335	0.0015	0.1281	0.0351	0.05491	0.1020	0.0824	0.0481	0.0781
	R^2	0.9835	0.9770	0.9194	0.9793	0.97483	0.9346	0.9501	0.9727	0.9496
Logarithimic	a	1.3901	0.9261	0.8435	0.9446	0.9878	0.8225	0.8497	0.8851	0.8212
	k	0.0012	0.0060	0.0132	0.0053	0.0076	0.0107	0.0109	0.0079	0.0102
	c	-0.4118	0.0895	0.1994	0.0421	0.0970	0.1955	0.1800	0.1384	0.2043
	χ^2	0.0007	0.0014	0.0005	0.0013	0.0015	0.0013	0.0005	0.0010	0.0006
	SSE	0.0203	0.0362	0.0119	0.0343	0.0395	0.0325	0.0134	0.0264	0.0152
	R^2	0.9896	0.9786	0.9922	0.9798	0.9811	0.9783	0.9916	0.9844	0.9898
Page	k	0.0011	0.0066	0.0272	0.0068	0.0041	0.0204	0.0193	0.0097	0.0185
	n	1.1050	0.9440	0.7271	0.9379	1.0642	0.7646	0.7840	0.8942	0.7732
	χ^2	0.0009	0.0014	0.0024	0.0013	0.0022	0.0024	0.0017	0.0015	0.0015
	SSE	0.0277	0.0378	0.0653	0.0341	0.0595	0.0648	0.0466	0.0406	0.0411
	R^2	0.9863	0.9785	0.9590	0.9791	0.9726	0.9585	0.9717	0.9769	0.9735
Avhad and Marchetti	a	0.9548	1.0307	1.0672	0.9961	1.0609	1.0405	1.0534	1.0300	1.0497
	k	0.0004	0.0088	0.0381	0.0066	0.0068	0.0262	0.0264	0.0122	0.0252
	n	1.2438	0.8958	0.6735	0.9447	0.9780	0.7239	0.7330	0.8557	0.7230
	χ^2	0.0008	0.0014	0.0023	0.0013	0.0020	0.0024	0.0016	0.0015	0.0014
	SSE	0.0224	0.0361	0.0585	0.0341	0.0508	0.0621	0.0421	0.0385	0.0372
	R^2	0.9885	0.9786	0.9618	0.9791	0.9757	0.9587	0.9735	0.9773	0.9751

Table 6.7. Arrhenius equation data of different drying models

Samples	Moisture diffusivity (m^2/s)	R^2
Control-P	6.06109×10^{-9}	0.87
ALB-5P	1.33271×10^{-8}	0.88
ALB-10P	1.86587×10^{-8}	0.90
WPC-5P	1.34001×10^{-8}	0.89
WPC-10P	1.58465×10^{-8}	0.87
SPC-5P	1.50067×10^{-8}	0.92
SPC-10P	1.80738×10^{-8}	0.89
GEL-5P	1.53718×10^{-8}	0.90
GEL-10P	1.58303×10^{-8}	0.91

6.3.4.2. Flowability and cohesiveness

In control powder (Table 6.8), a greater difference between bulk and tap density (0.14 g/mL) was seen as compared to foam mat dried powders (0.04 to 0.11 g/mL), which indicated it to have poor flow properties [11]. Carr index categorized ALB, WPC, and SPC at both concentrations as having very good flowability, GEL-5P and GEL-10P as having good flowability, and the control sample to have poor flowability (Table 6.2). From Hausner ratio, it was deduced that all the powders had low cohesiveness except the control and GEL-5P and GEL-10P (Table 6.3). The free flowing and low cohesiveness characteristics of the foam mat dried powders can find use in beverages, soups, etc.

6.3.4.3. Wettability

The wettability time of the foam mat dried powders was found in the range of 114-121 s and in control sample it was 131.00 s (Table 6.8). It was noticed that as the concentration of the foaming agents was increased, the wettability time of the powder decreased. This may be attributed to the more porous structure of these powders that allowed for easy movement of water within the powder. In foam mat dried date powder, increase in foaming agent from 40 to 50% led to a significant decrease in the wettability of the powder [42].

6.3.4.4. Solubility

Solubility of a food powder is very essential for evaluating its reconstitution properties. The solubility of foam mat powders was found to have increased in all the powders in comparison to control powder. The solubility of foam mat dried powders ranged from 88.86-91.25%, while in control sample it was 92.03% (Table 6.8). Significant difference was found in solubility of powder obtained by the addition of foaming agents. The lowest water solubility index was found in GEL-5P and the highest was shown by WPC-10P, indicating an effect of concentration of foaming agent. The increase in solubility is related to the porosity of powder and addition of high protein content leads to increase in porosity [1]. Foams with higher expansion have higher solubility [43], therefore WPC-10F with maximum foam expansion also showed highest solubility. Solubility is considered to be one of the main criteria for developing instant powder food products [44], thus powder prepared with WPC at 10% concentration can be useful to develop tamarillo powder.

6.3.4.5. Hygroscopicity

Hygroscopicity of powder is required to determine the shelf life stability of the product over time. Addition of foaming agents and varying their concentration exerted significant differences on the hygroscopicity of the foam mat dried tamarillo powder (Table 6.8). The reduction in hygroscopicity was between 11.44% (GEL-5P) and 45.33% (WPC-10P) as compared to control samples. Lowest hygroscopicity was seen for WPC-5P and WPC-10P, which clearly indicates the efficiency of WPC as a foaming agent.

6.3.4.6. Colour parameters

Foaming agents at the concentrations used were found to significantly affect the L*, a* and b* parameters of foam mat dried powder samples (Table 6.8). Lightness increased, and redness and yellowness decreased in comparison to the control sample. There was no significant difference in lightness of powder obtained using WPC and SPC at 10%, whereas significant difference was found for samples with albumin and gelatin at 10%. Similar trend of increase in the lightness values with increase in the egg albumin was reported for production of pineapple powder [43]. Due to higher foam expansion at higher concentration of foaming agents, the powders have greater porous structure that entraps more air, which

lightens the colour of the powders [43]. Seerangurayar et al. [42] also observed a decrease in a* values of date foam dried powder with increase in the foaming agents. The colour of tamarillo powder is due the presence of the carotenoids compounds, especially β-carotene and β-cryptoxanthin, and anthocyanins [34, 48]. The decrease in b* value is related to degradation of carotenoids during production of foam, as carotenoids are very susceptible to oxygen and light. Similar observation was reported for foam mat dried mango powder [12], and pineapple foam mat powder at concentration of 5 and 10% [43]. Changes in a* and b* values on foam mat drying affected the hue angles and chroma values. The highest hue angle and chroma were recorded for WPC-10P and lowest for GEL-5P. Thus, addition of foaming agent at higher concentration helps in protecting the pigments like carotenoids during the drying period [24].

6.3.5. Scanning electron microscopy (SEM)

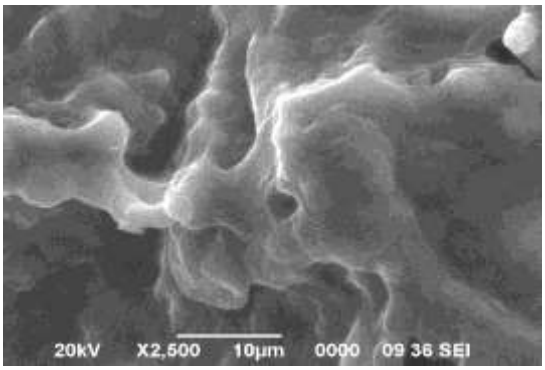
SEM images were used to understand the effect of addition of different foaming agents and their concentration on the morphology of foam mat dried powders. It was noted that concentration of foaming agents strongly affected the structure and morphology of the dried foams (Fig. 6.2.). Foam structure on drying retains a porous microstructure in the powdered material. Different microstructure was obtained for different foaming agents. Among all the foaming agents, WPC samples showed good microstructures, however, increase in WPC concentration from 5 to 10% maximized the number of pores and extended the pore size. Increase in pore size in microstructures of the powder tends to increase the solubility of the powder with better retention of phytochemicals. Thuwapanichayanan et al. [46] studied the effect of egg albumin, soy protein isolate and whey protein concentrate on banana foam and found that good microstructure was retained by whey protein concentrate. As seen in Fig. 6.2, SPC and ALB also exhibited good microstructures in terms of void formation after drying, but GEL powders were found to be very compact in nature. The compact nature of GEL microstructure may be due to unstable foams caused by the fibrous structure of gelatin.

Table 6.8. Powder characteristics of foam mat dried powder

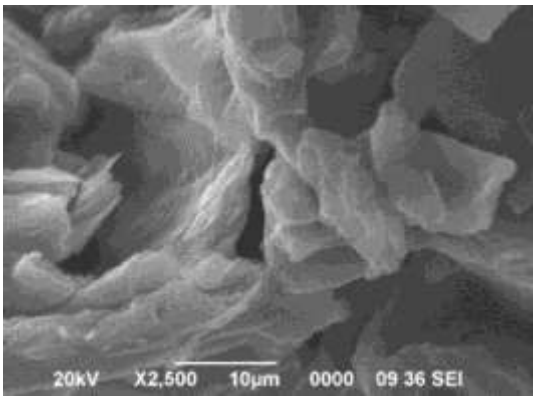
Sample code	Bulk density (g/mL)	Tapped density (g/mL)	Carr index	Hausner ratio	Wettability (s)	Solubility (%)	Hygroscopicity (%)	L*	a*	b*	Hue	Chroma
Control-P	0.40 ± 0.01^{g}	0.54 ± 0.00^{e}	26.81 ± 2.53^{a}	1.36 ± 0.04^{a}	131.00 ± 2.82^{a}	92.03 ± 0.85^{a}	24.20 ± 0.25^{a}	60.61 ± 0.16^{e}	14.85 ± 0.14^{a}	34.73 ± 0.06^{a}	66.84 ± 0.11^{c}	37.77 ± 0.11^{a}
ALB-5P	0.49 ± 0.01^{de}	0.53 ± 0.02^{f}	7.51 ± 3.11^{c}	1.08 ± 0.03^{c}	121.67 ± 1.57^{b}	89.05 ± 0.19^{d}	18.77 ± 0.15^{c}	62.60 ± 0.26^{d}	14.70 ± 0.09^{a}	29.87 ±0.22^{d}	63.77 ± 0.30^{e}	33.31 ± 0.17^{d}
ALB-10P	0.47 ± 0.01^{e}	0.51 ± 0.05^{g}	9.02 ± 2.17^{c}	1.09 ± 0.02^{c}	116.30 ± 1.00^{c}	89.18 ± 0.52^{d}	16.63 ± 0.21^{d}	66.08 ± 0.05^{b}	13.45 ± 0.22^{d}	29.42 ± 0.27^{e}	65.46 ± 0.56^{d}	32.35 ± 0.15^{e}
WPC-5P	0.52 ± 0.01^{c}	0.59 ± 0.00^{c}	11.86 ± 1.69^{c}	1.13 ± 0.02^{c}	120.00 ± 2.08^{b}	89.60 ± 0.08^{b}	13.73 ± 0.11^{e}	64.84 ± 0.56^{c}	14.30 ± 0.24^{b}	31.16 ± 0.15^{b}	65.38 ± 0.29^{d}	34.29 ± 0.24^{bc}
WPC-10P	0.50 ± 0.01^{d}	0.56 ± 0.01^{d}	10.68 ± 2.90^{c}	1.12 ± 0.03^{c}	116.00 ± 1.01^{c}	91.19 ± 0.16^{a}	13.23 ± 0.15^{g}	69.88 ± 0.35^{a}	13.86 ± 0.18^{c}	31.15 ± 0.37^{b}	66.30 ± 0.25^{c}	34.43 ± 0.39^{b}
SPC-5P	0.57 ± 0.02^{a}	0.64 ± 0.01^{a}	11.39 ± 3.22^{c}	1.12 ± 0.04^{c}	119.00 ± 0.50^{b}	89.34 ± 0.31^{d}	14.91 ± 0.19^{e}	64.38 ± 0.89^{c}	12.72 ± 0.22^{f}	29.63 ± 0.02^{de}	66.80 ± 0.37^{c}	32.25 ± 0.10^{e}
SPC-10P	0.55 ± 0.01^{b}	0.61 ± 0.01^{b}	10.23 ± 1.84^{c}	1.11 ± 0.02^{c}	116.67 ± 1.15b	89.25 ± 0.11^{cd}	14.23 ± 0.23^{f}	70.52 ± 0.25^{a}	11.57 ± 0.25^{g}	30.71 ± 0.04^{c}	69.38 ± 0.42^{a}	32.82 ± 0.09^{d}
GEL-5P	0.48 ± 0.01^{de}	0.59 ± 0.01^{c}	18.61 ± 2.64^{b}	1.22± 0.04^{b}	117.66 ± 0.57^{c}	88.86 ± 0.25^{e}	21.43 ± 0.21^{b}	61.96 ± 0.38^{d}	13.76 ± 0.17^{cd}	25.70 ± 0.11^{f}	65.41 ± 0.19^{d}	33.04 ± 0.17^{d}
GEL-10P	0.44 ± 0.02^{f}	0.54 ± 0.05^{e}	19.01 ± 2.03^{b}	1.22 ± 0.03^{b}	114.00 ± 1.73^{d}	89.52 ± 0.25^{c}	18.60 ± 0.13^{c}	64.34 ± 0.19^{c}	13.06 ± 0.04^{e}	31.37 ± 0.14^{b}	67.43 ± 0.09^{b}	33.98 ± 0.14^{c}

Values are expressed in mean ± standard deviation, the different letter on top (a-g), indicate the significant difference between column ($P<0.05$) between means according to Duncan's multiple range test.

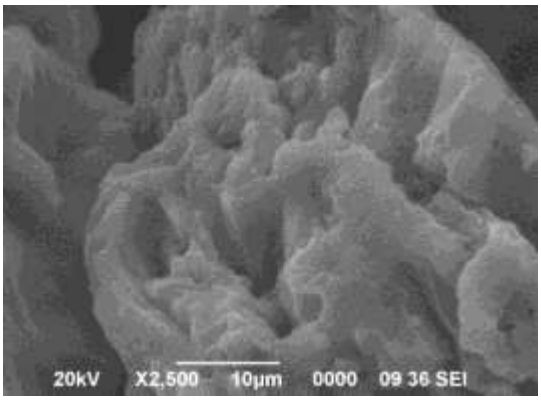
Though SPC and ALB showed acceptable microstructures, irregularity in structures were noticed, as also observed by Franco et al. [20] in yacon foam mat dried juice. Abbasi and his co-workers [1] developed foam mat dried shrimp powder and reported that enhanced solubility of foam mat dried powders is related to morphology and microstructure of processed powder. Thus, WPC-10P that has good microstructure also exhibited highest solubility.



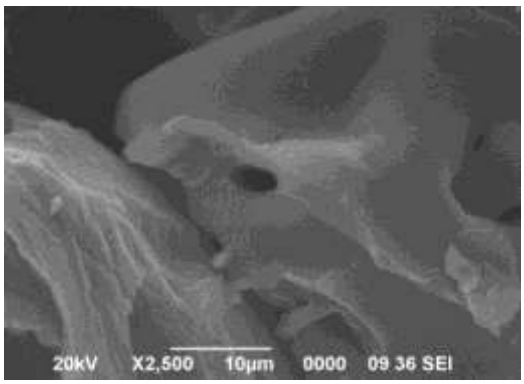
Control-P



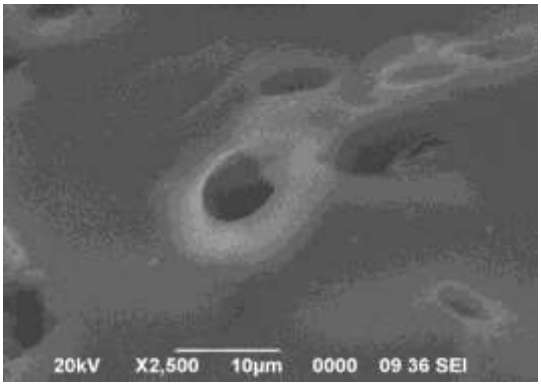
ALB-5P



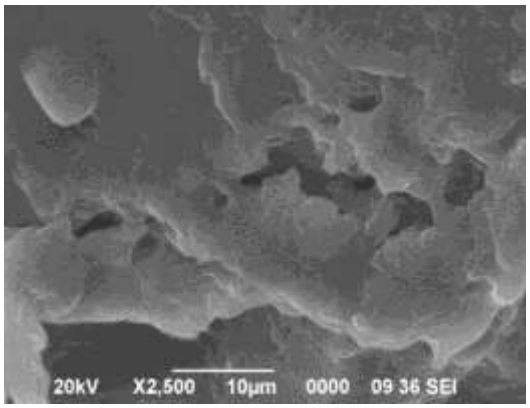
ALB -10P



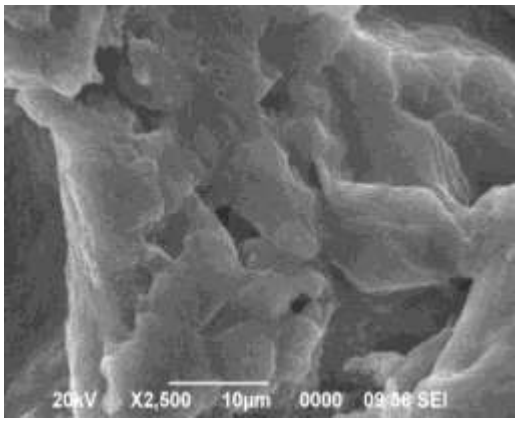
WPC-5P



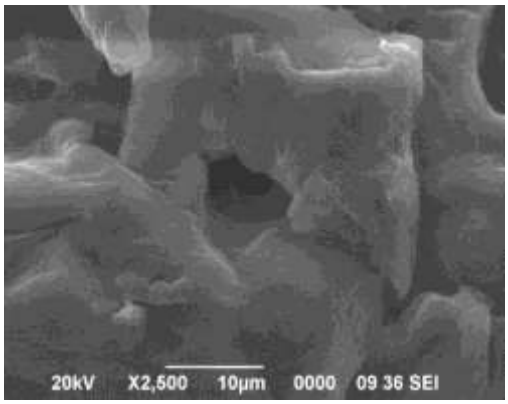
WPC -10P



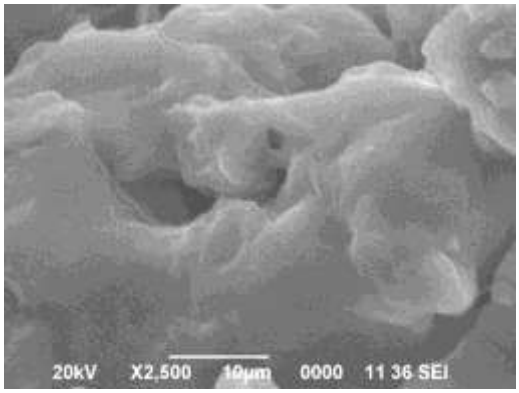
SPC-5P



SPC-5P



GEL-5P



GEL -10P

Fig. 6.2. SEM images of foam mat dried powder obtained using different foaming agent and concentration at x2500 magnification.

6.3.6. Effect of foaming agents on TPC, TPC, total carotenoids, and *in-vitro* antioxidant properties of powder samples

TPC of foam mat dried powders ranged from 714-769 mg GAE/100 g. Concentration of foaming agent significantly and positively affected the content (Table 6.9). An increase of approx. 77% of phenolic content was found in WPC-10P and 64% increase in phenolic content was depicted by GEL-5P in comparison to control sample. The increase in TPC can be due to better release of bioactive compounds in WPC-10P, which also registered maximum solubility [37]. The other main reason of the increase in phenolic content is the release of bound phenolic compounds during foam preparation by whipping.

TFC in control sample was found to be 63.16 QE/100g and in foam mat powders the range was in between 104.36-116.32 mg QE/100g. A significant and positive effect was exhibited with increase in concentration of the foaming agents (Table 6.9). The highest activity was exhibited by WPC followed by SPC and ALB, and least activity was shown by GEL. The reduction in drying time due to increased surface area of foam protected the degradation of bioactive compounds during drying [43].

Use of different foaming agents at different concentrations significantly affected the total carotenoids content (Table 6.9). The total carotenoids in the foam mat tamarillo powder ranged from 1.65-1.71 mg β-CE/g of sample; lowest activity was exhibited by GEL-5P and highest activity by WPC-10P and SPC-10P. However, the carotenoids in control sample were high in relation to foam mat powders with the value of 1.81 mg β-CE/g. Because carotenoids are particularly sensitive to oxygen and light, the whipping operation during foam development exposed these beneficial chemicals to a high level of oxygen and light, thereby increasing the risk of destruction [9]. Our results of low values of carotenoids content in foam mat powders are also supported by Kandasamy et al. [27]. As seen in Table 6, increasing the foaming agent concentration to 10% increased the carotenoids content as the exposure time to oxygen was reduced due to shortened drying time [12, 24].

Foaming process prevented the degradation of bioactive compounds and a significant difference in the antioxidant activities of the powders were found (Table 6.9). The DPPH radical activity of control sample was 27.09% and in foam mat dried powders it was in the range of 41.36-49.25%. An increase of 81.80% in DPPH activity was shown by WPC-10P and lowest activity of 52.67% was seen in GEL-5P in comparison to raw sample (Table 6). The total phenolic content and flavonoids content play an important role in exhibiting the

antioxidant potential. Our results of phenolic content and flavonoids content were reflected in the radical scavenging activity of the powders. Except for WPC, increase in concentration of the foaming agent significantly increased the antioxidant activity,

The ABTS radical scavenging activity in the raw sample extract was 31.02%, and in foam mat powder it was in the range of 49.56-57.86% (Table 6.9). The highest activity was possessed by WPC-10P (85% increase from control value) and lowest activity was shown by GEL-5P (60% increase from control value). Significant difference in ABTS radical scavenging activity on addition of foaming agent concentration was found. The activity was related to retention and protection of bioactive compounds during drying by foaming agents.

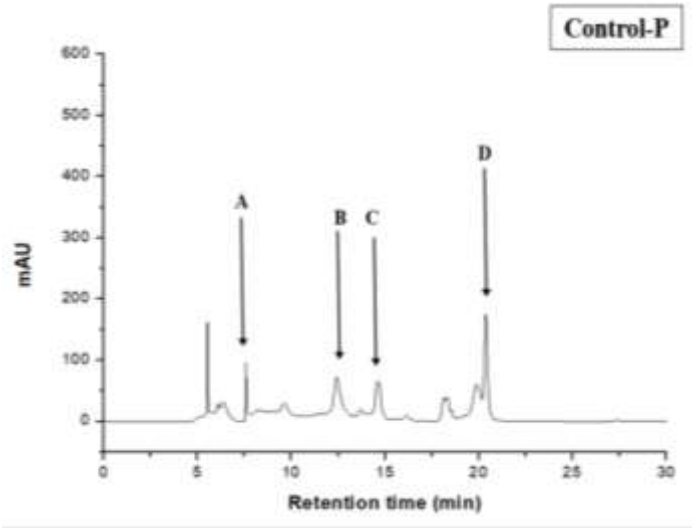
Table 6.9. Phenolic, flavonoids, *in-vitro* antioxidant values of the foam mat dried powders

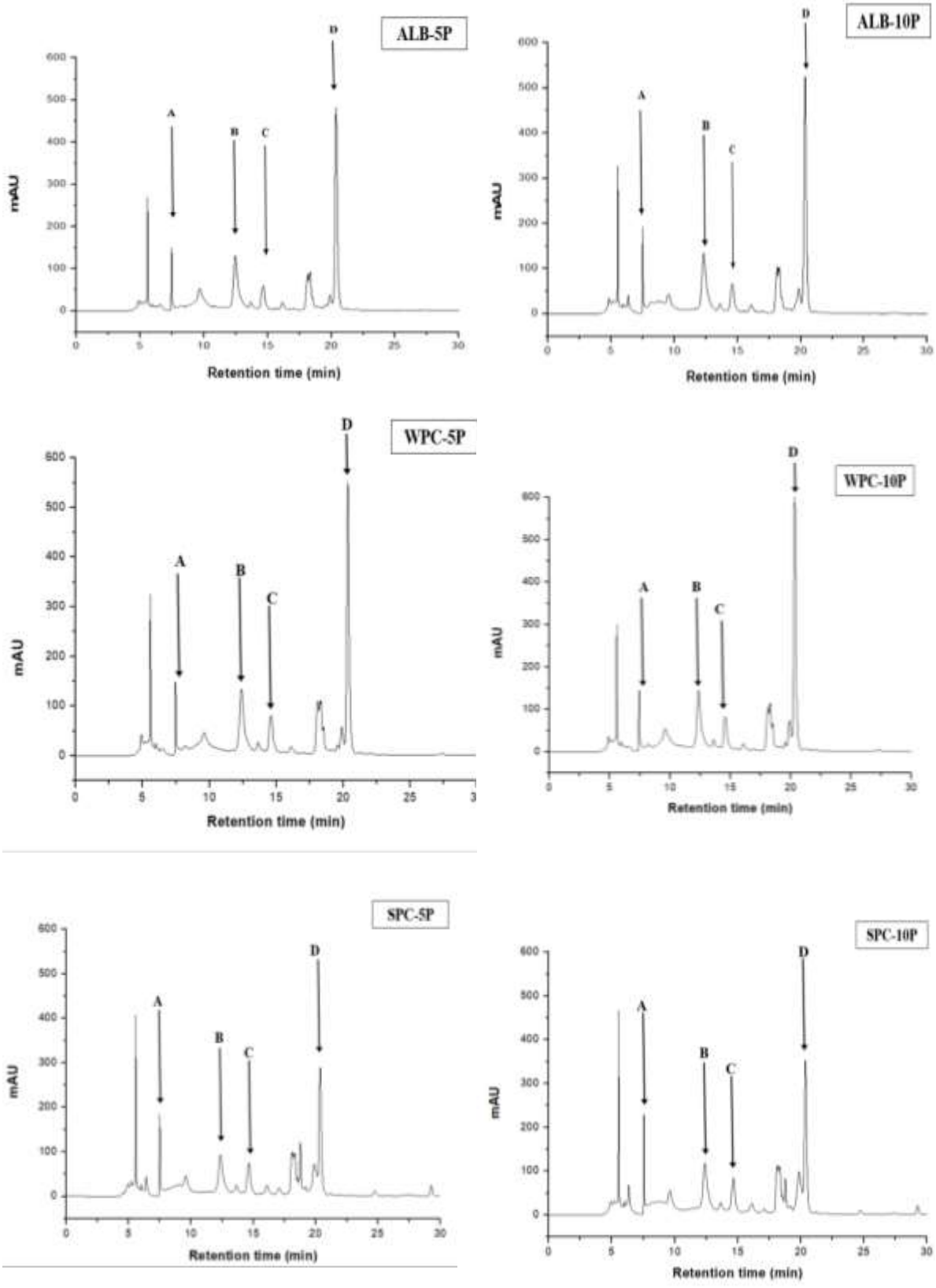
Sample code	TPC (mg GAE/100g)	TFC (mg QE/100g)	Total carotenoids (mg βCE/g)	DPPH (%)	ABTS (%)	MCC (%)
Control-P	433.91 ± 0.16^{i}	63.16 ± 0.72^{g}	1.81 ± 0.04^{a}	19.67 ± 0.76^{g}	31.02 ± 0.59^{g}	28.56 ± 0.33^{h}
ALB-5P	725.23 ± 0.65^{g}	106.25 ± 0.65^{e}	1.65 ± 0.02^{e}	43.25 ± 0.43^{e}	51.23 ± 0.65^{e}	36.54 ± 0.25^{e}
ALB-10P	732.25 ± 0.54^{f}	108.35 ± 0.48^{d}	1.68 ± 0.02^{c}	44.36 ± 0.42^{d}	53.25 ± 0.57^{d}	39.54 ± 0.36^{d}
WPC-5P	763.12 ± 0.45^{b}	112.32 ± 0.58^{b}	1.69 ± 0.02^{c}	48.35 ± 0.83^{a}	54.23 ± 0.23^{c}	41.25 ± 0.31^{b}
WPC-10P	769.31 ± 0.56^{a}	116.32 ± 0.52^{a}	1.71 ± 0.02^{b}	49.25 ± 0.72^{a}	57.68 ± 0.48^{a}	43.26 ± 0.36^{a}
SPC-5P	742.32 ± 0.53^{e}	111.25 ± 0.69^{c}	1.67 ± 0.03^{c}	45.63 ± 0.69^{c}	53.23 ± 0.46^{d}	40.23 ± 0.54^{c}
SPC-10P	756.32 ± 0.32^{c}	112.12 ± 0.16^{b}	1.70 ± 0.03^{b}	46.85 ± 0.16^{b}	56.54 ± 0.54^{b}	41.36 ± 0.26^{b}
GEL-5P	714.25 ± 0.13^{h}	104.36 ± 0.72^{f}	1.62 ± 0.01^{f}	41.36 ± 0.72^{f}	49.56 ± 0.59^{f}	32.36 ± 0.59^{g}
GEL-10P	752.63 ± 0.50^{d}	110.21 ± 0.54^{c}	1.64 ± 0.02^{e}	45.65 ± 0.54^{c}	52.65 ± 0.35^{d}	35.45 ± 0.64^{f}

Values are expressed in mean ± standard deviation, the different letter on top (a-h), indicate the significant difference between column ($P<0.05$) between means according to Duncan's multiple range test.

6.3.7. HPLC analysis of phenolic acids present in foam mat dried powders

The phenolic acids present in the control and foam mat dried powders were analyzed using HPLC. In Figure 6.3, four phenolic acids were identified in the control and foam mat dried powder samples. The identified phenolic acids found in the sample were gallic acid, chlorogenic acid, caffeic acid, and p-coumaric acid. Increase in the concentration of phenolic acids was found in all the foam mat powders as compared to the raw, with maximum concentration of gallic acid, followed by chlorogenic acids, p-coumaric acid, and caffeic acid, in that order. The highest concentration of phenolic acids was recorded in WPC-10P, and GEL-5P had the lowest content. The highest concentration in WPC-10P may be due to solubility and good microstructure of the powder (Table 6.10). Thus, highest solubility and better porous structure results in better retention of phenolic acids. The HPLC chromatograms revealed that increase in the concentration of foaming agents enhanced the retention of bioactive compounds. Diep et al. [18] profiled the phenolic acids present in tamarillo pulp and reported that gallic, chlorogenic, caffeic and p-coumaric acid were present in the pulp of yellow, red and purple varieties of tamarillos, which is in agreement with our results. However, only chlorogenic, caffeic, and p-coumaric acids were reported in the tamarillo fruit obtained from Ecuador and New Zealand [19].




ALB-5P
ALB-10P
WPC-5P
WPC-10P
SPC-5P
SPC-10P
A
B
C
D
mAU
Retention time (min)

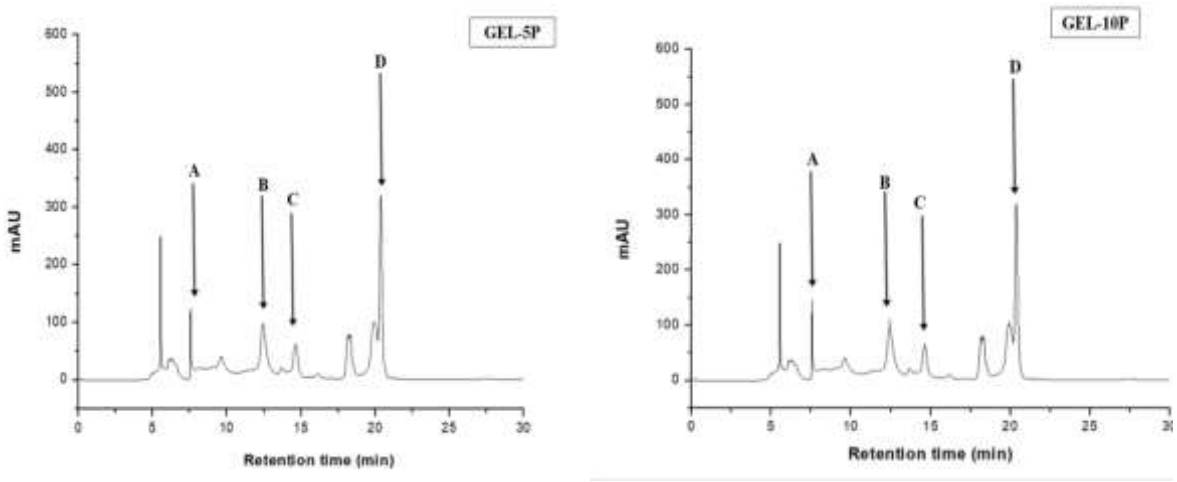
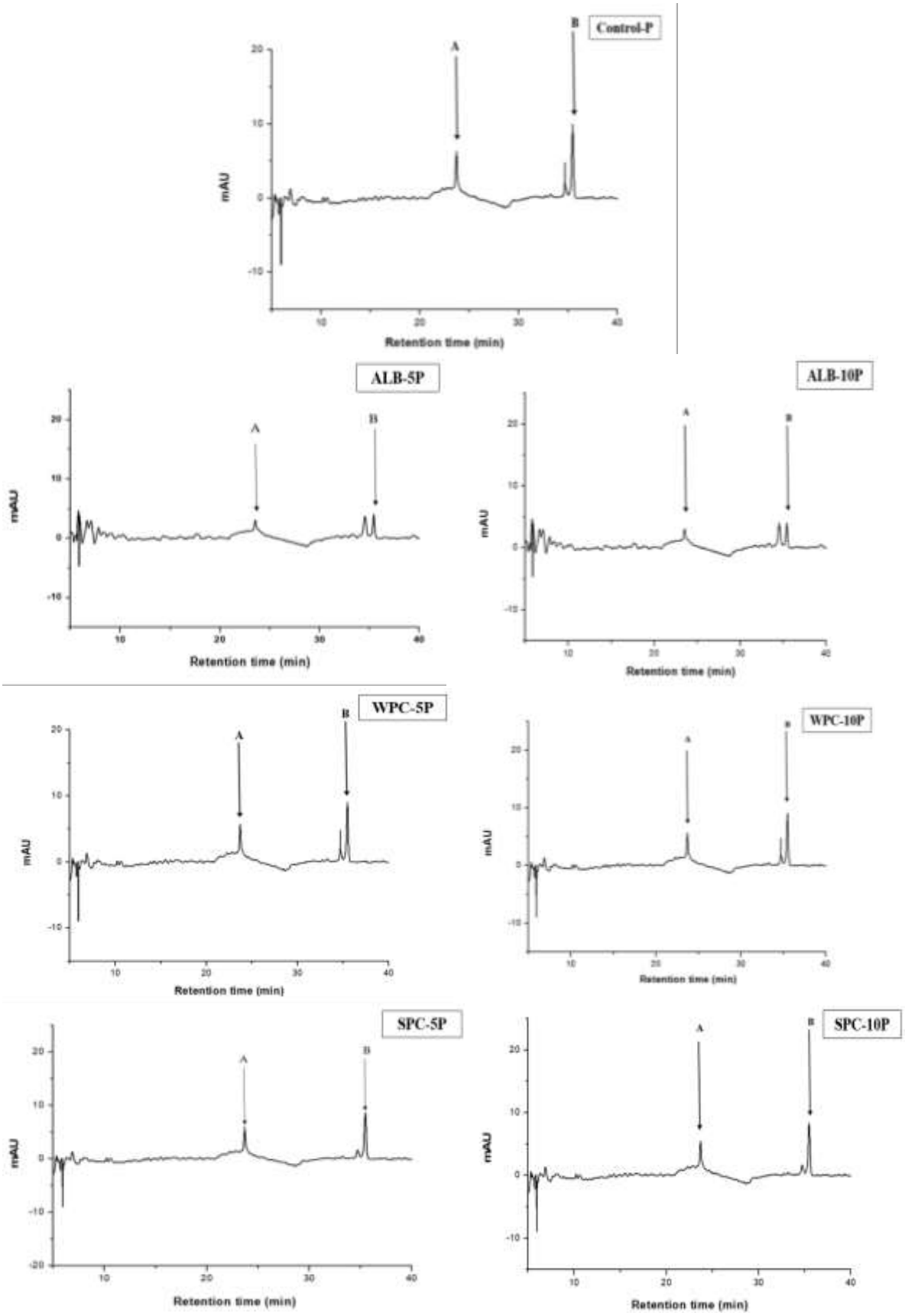


Fig. 6.3. HPLC chromatograms of different foam mat dried tamarillo powders; A: gallic acid, B: chlorogenic acid, C: caffeic acid and D: p-coumaric acid

6.3.8 HPLC of carotenoids present in foam mat dried powders

The carotenoids present in the foam mat dried tamarillo powders were analyzed using HPLC. Mertz et al. [34] profiled the carotenoids present in tamarillo fruit and reported that β-cryptoxanthin and β-carotene make up the major amount of the carotenoids. In Fig. 6.4, two major carotenoids, β-cryptoxanthin and β-carotene were identified (Table 6.10). In the control sample, the concentration of β-cryptoxanthin and β-carotene was 29.36 and 38.95 μg/g, which is higher in comparison to all foam mat dried powders. Though lesser carotenoids content in foam mat powders, it was noticed that increase in the concentration of foaming agents improved the carotenoids content in all the foam mat powders. Furthermore, these results support the discussion for higher total carotenoids content with higher concentration of foaming agent in section 3.7. In foam mat powders, the highest retention was found in WPC-10P with the concentration of 27.47 μg/g and 19.47 μg/g of β-cryptoxanthin and β-carotene, respectively, and the lowest retention was shown by GEL-5P.


Control-P
A
B
mAU
Retention time (min)
ALB-5P
ALB-10P
WPC-5P
WPC-10P
SPC-5P
SPC-10P

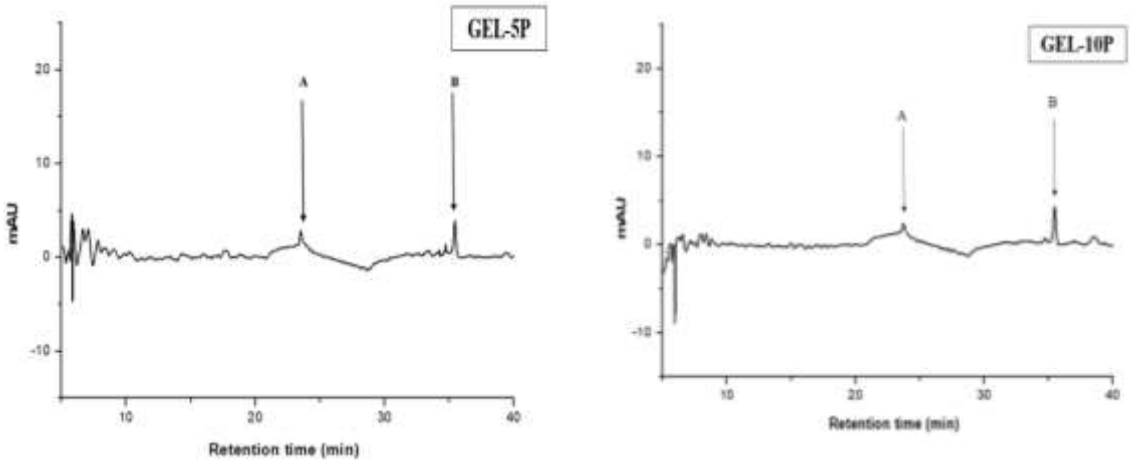


Fig. 6.4. HPLC chromatograms of carotenoids present in different foam mat dried tamarillo powders; A: β-cryptoxanthin, B: β-carotene.

Table 6.10. Phenolic acid and carotenoids concentration identified in samples.

Sample code	Phenolic acids identified (µg/g)				Carotenoids (µg/g)	
	Gallic acid	Chlorogenic Acid	Caffeic acid	p-coumaric acid	β-cryptoxanthin	β-carotene
Control-P	226.36	159.36	28.63	147.35	29.36	38.95
ALB-5P	519.81	346.11	59.74	269.26	21.15	13.57
ALB-10P	723.29	294.78	74.86	251.36	23.87	16.91
WPC-5P	776.71	423.94	67.5	346.13	24.92	13.74
WPC-10P	890.16	403.05	84.98	297.51	27.47	19.47
SPC-5P	644.06	324.55	56.38	192.59	25.23	14.21
SPC-10P	672.87	356.97	75.32	319.52	26.64	18.87
GEL-5P	262.31	330.96	42.16	133.93	22.71	12.25
GEL-10P	475.99	338.99	52.53	248.48	23.88	15.39

6.4. Conclusion

Four foaming agents (ALB, WPC, SPC and GEL) at two different levels (5 and 10%) were used for the development of foam mat dried powders from tamarillo pulp. Concentration of foaming agents plays an important role in determining the properties of foam and influences the properties of the powder. Foam obtained by WPC-10F registered foam density of 0.64 g/cm^3, expansion of 52.25%, and highest stability of 98.4%. Experimental results showed that powder prepared using SPC showed good bulk density and tapped density, but WPC allowed for better retention of bioactive compounds and possessed desirable powder properties too. HPLC showed better concentration of phenolic acids in foam mat dried powders as compared to the control and increase in concentration of foaming agent had positive effect on phenolic acids and carotenoids content. Therefore, even though all the foaming agents helped to improve the quality of the dried powders as compared to control sample, there were differences in the properties, with WPC showing desirable effects followed by SPC, ALB and GEL, in that order. Probably, the fibrous structure of the gelatin protein may have a role in the results. WPC also retained the bioactive compounds with minimal destruction. Foam mat dried powder has high potential to be used as a reconstituted drink, in instant soup, or as a food additive in novel foods.

Bibliography

[1] Abbasi, E. and Azizpour, M., Evaluation of physicochemical properties of foam mat dried sour cherry powder. *LWT*, 68:105-110, 2016.

[2] Abd Karim, A. and Wai, C.C., Foam-mat drying of starfruit (*Averrhoa carambola* L.) puree. Stability and air drying characteristics. *Food Chemistry*, 64(3):337-343, 1999.

[3] Al Mubarak, A., Hamid, N., Kam, R., and Chan, H., The effects of spray drying conditions on the physical and bioactive properties of New Zealand Tamarillo (*Solanum betaceum*) powder. *Acta Scientific Nutritional Health*, 3(12):121-131, 2019.

[4] Asokapandian, S., Venkatachalam, S., Swamy, G.J., and Kuppusamy, K., Optimization of foaming properties and foam mat drying of muskmelon using soy protein. *Journal of Food Process Engineering*, 39(6):692-701, 2016.

[5] Avhad, M. and Marchetti, J., Mathematical modelling of the drying kinetics of Hass avocado seeds. *Industrial Crops and Products,* 91:76-87, 2016.

[6] Ayetigbo, O., Latif, S., Abass, A., and Müller, J., Drying kinetics and effect of drying conditions on selected physicochemical properties of foam from yellow-fleshed and white-fleshed cassava (*Manihot esculenta*) varieties. *Food and Bioproducts Processing,* 127:454-464, 2021.

[7] Azeez, L., Adebisi, S.A., Oyedeji, A.O., Adetoro, R.O., and Tijani, K.O., Bioactive compounds' contents, drying kinetics and mathematical modelling of tomato slices influenced by drying temperatures and time. *Journal of the Saudi Society of Agricultural Sciences,* 18(2):120-126, 2019.

[8] Benković, M., Pižeta, M., Tušek, A.J., Jurina, T., Kljusurić, J.G., and Valinger, D., Optimization of the foam mat drying process for production of cocoa powder enriched with peppermint extract. *LWT,* 115:108440, 2019.

[9] Branco, I.G., Kikuchi, T.T., Argandoña, E.J.S., Moraes, I.C.F., and Haminiuk, C.W.I., Drying kinetics and quality of uvaia (*Hexachlamys edulis* (O. Berg)) powder obtained by foam-mat drying. *International Journal of Food Science & Technology,* 51(7):1703-1710, 2016.

[10] BRITTEN, M. and LAVOIE, L., Foaming properties of proteins as affected by concentration. *Journal of Food Science,* 57(5):1219-1241, 1992.

[11] Chandrasekar, V., Gabriela, J.S., Kannan, K., and Sangamithra, A., Effect of foaming agent concentration and drying temperature on physiochemical and antimicrobial properties of foam mat dried powder. *Asian J. Dairy Food Res,* 34:39-43, 2015.

[12] Chaux-Gutiérrez, A.M., Santos, A.B., Granda-Restrepo, D.M., and Mauro, M.A., Foam mat drying of mango: Effect of processing parameters on the drying kinetic and product quality. *Drying Technology,* 35(5):631-641, 2017.

[13] Das Purkayastha, M., Nath, A., Deka, B.C., and Mahanta, C.L., Thin layer drying of tomato slices. *Journal of Food Science and Technology,* 50(4):642-653, 2013.

[14] de Carvalho Tavares, I.M., Sumere, B.R., Gómez-Alonso, S., Gomes, E., Hermosín-Gutiérrez, I., Da-Silva, R., and Lago-Vanzela, E.S., Storage stability of the phenolic compounds, color and antioxidant activity of jambolan juice powder obtained by foam mat drying. *Food Research International,* 128:108750, 2020.

[15] de Carvalho, T.I.M., Nogueira, T.Y.K., Mauro, M.A., Gómez-Alonso, S., Gomes, E., Da-Silva, R., Hermosín-Gutiérrez, I., and Lago-Vanzela, E.S., Dehydration of

jambolan [*Syzygium cumini* (L.)] juice during foam mat drying: quantitative and qualitative changes of the phenolic compounds. *Food Research International,* 102:32-42, 2017.

[16] de Cól, C.D., Tischer, B., Flôres, S.H., and Rech, R., Foam-mat drying of bacaba (*Oenocarpus bacaba*): Process characterization, physicochemical properties, and antioxidant activity. *Food and Bioproducts Processing,* 126:23-31, 2021.

[17] Dehghannya, J., Pourahmad, M., Ghanbarzadeh, B., and Ghaffari, H., Heat and mass transfer modeling during foam-mat drying of lime juice as affected by different ovalbumin concentrations. *Journal of Food Engineering,* 238:164-177, 2018.

[18] Diep, T., Pook, C., and Yoo, M., Phenolic and anthocyanin compounds and antioxidant activity of tamarillo (*Solanum betaceum* Cav.). *Antioxidants,* 9(2):169, 2020.

[19] Espín, S., Gonzalez-Manzano, S., Taco, V., Poveda, C., Ayuda-Durán, B., Gonzalez-Paramas, A.M., and Santos-Buelga, C., Phenolic composition and antioxidant capacity of yellow and purple-red Ecuadorian cultivars of tree tomato (*Solanum betaceum* Cav.). *Food Chemistry,* 194:1073-1080, 2016.

[20] Franco, T.S., Perussello, C.A., Ellendersen, L.N., and Masson, M.L., Effect of process parameters on foam mat drying kinetics of yacon (*Smallanthus sonchifolius*) and thin-layer drying modeling of experimental data. *Journal of Food Process Engineering,* 40(1):e12264, 2017.

[21] García, J.M., Giuffrida, D., Dugo, P., Mondello, L., and Osorio, C., Development and characterisation of carotenoid-rich microencapsulates from tropical fruit by-products and yellow tamarillo (*Solanum betaceum* Cav.). *Powder Technology,* 339:702-709, 2018.

[22] Hardy, Z. and Jideani, V.A., Foam-mat drying technology: A review. *Critical Reviews in Food Science and Nutrition,* 57(12):2560-2572, 2017.

[23] Henry, L.K., Puspitasari-Nienaber, N.L., Jarén-Galán, M., van Breemen, R.B., Catignani, G.L., and Schwartz, S.J., Effects of ozone and oxygen on the degradation of carotenoids in an aqueous model system. *Journal of Agricultural and Food Chemistry,* 48(10):5008-5013, 2000.

[24] Hossain, M., Mitra, S., Belal, M., and Zzaman, W., Effect of foaming agent concentration and drying temperature on biochemical properties of foam mat dried tomato powder. *Food Research,* 5(1):291-297, 2021.

[25] Hsu, B., Pu, Y., Inbaraj, B.S., and Chen, B., An improved high performance liquid chromatography–diode array detection–mass spectrometry method for determination of carotenoids and their precursors phytoene and phytofluene in human serum. *Journal of Chromatography B,* 899:36-45, 2012.

[26] Jha, A.K. and Sit, N., Drying characteristics and kinetics of colour change and degradation of phytocomponents and antioxidant activity during convective drying of deseeded *Terminalia chebula* fruit. *Journal of Food Measurement and Characterization,* 14(4):2067-2077, 2020.

[27] Kandasamy, P., Varadharaju, N., Kalemullah, S., and Maladhi, D., Optimization of process parameters for foam-mat drying of papaya pulp. *Journal of Food Science and Technology,* 51(10):2526-2534, 2014.

[28] Li, T.S., Sulaiman, R., Rukayadi, Y., and Ramli, S., Effect of gum Arabic concentrations on foam properties, drying kinetics and physicochemical properties of foam mat drying of cantaloupe. *Food Hydrocolloids,* 116:106492, 2021.

[29] Link, J.V., Tribuzi, G., and Laurindo, J.B., Improving quality of dried fruits: A comparison between conductive multi-flash and traditional drying methods. *LWT,* 84:717-725, 2017.

[30] Lobo, F.A., Nascimento, M.A., Domingues, J.R., Falcão, D.Q., Hernanz, D., Heredia, F.J., and de Lima Araujo, K.G., Foam mat drying of Tommy Atkins mango: Effects of air temperature and concentrations of soy lecithin and carboxymethylcellulose on phenolic composition, mangiferin, and antioxidant capacity. *Food Chemistry,* 221:258-266, 2017.

[31] Lomakina, K. and Mikova, K., A study of the factors affecting the foaming properties of egg white–a review. *Czech Journal of Food Sciences,* 24(3):110-118, 2006.

[32] Marboh, V. and Mahanta, C.L., Characterisation and antioxidant activity of sohphlang (*Flemingia vestita*), a tuberous crop. *Journal of Food Science and Technology,* 57(10):3533-3544, 2020.

[33] Marinova, K.G., Basheva, E.S., Nenova, B., Temelska, M., Mirarefi, A.Y., Campbell, B., and Ivanov, I.B., Physico-chemical factors controlling the foamability and foam stability of milk proteins: Sodium caseinate and whey protein concentrates. *Food Hydrocolloids,* 23(7):1864-1876, 2009.

[34] Mertz, C., Brat, P., Caris-Veyrat, C., and Gunata, Z., Characterization and thermal lability of carotenoids and vitamin C of tamarillo fruit (*Solanum betaceum* Cav.). *Food Chemistry,* 119(2):653-659, 2010.

[35] Ng, M.L. and Sulaiman, R., Development of beetroot (*Beta vulgaris*) powder using foam mat drying. *LWT,* 88:80-86, 2018.

[36] Qadri, O.S. and Srivastava, A.K., Effect of microwave power on foam-mat drying of tomato pulp. *Agricultural Engineering International: CIGR Journal,* 16(3):238-244, 2014.

[37] Ragaee, S., Seetharaman, K., and Abdel-Aal, E.-S.M., The impact of milling and thermal processing on phenolic compounds in cereal grains. *Critical Reviews in Food Science and Nutrition,* 54(7):837-849, 2014.

[38] Ramakrishnan, Y., Adzahan, N.M., Yusof, Y.A., and Muhammad, K., Effect of wall materials on the spray drying efficiency, powder properties and stability of bioactive compounds in tamarillo juice microencapsulation. *Powder Technology,* 328:406-414, 2018.

[39] Rodriguez-Amaya, D., Bobbio, P., and Bobbio, F., Carotenoid composition and vitamin A value of the brasilian fruit *Cyphomandra betacea*. *Food Chemistry,* 12(1):61-65, 1983.

[40] Saikia, S., Mahnot, N.K., and Mahanta, C.L., Phytochemical content and antioxidant activities of thirteen fruits of Assam, India. *Food Bioscience,* 13:15-20, 2016.

[41] Santhalakshmy, S., Bosco, S.J.D., Francis, S., and Sabeena, M., Effect of inlet temperature on physicochemical properties of spray-dried jamun fruit juice powder. *Powder Technology,* 274:37-43, 2015.

[42] Seerangurayar, T., Manickavasagan, A., Al-Ismaili, A.M., and Al-Mulla, Y.A., Effect of carrier agents on physicochemical properties of foam-mat freeze-dried date powder. *Drying Technology,* 36(11):1292-1303, 2018.

[43] Shaari, N.A., Sulaiman, R., Rahman, R.A., and Bakar, J., Production of pineapple fruit (*Ananas comosus*) powder using foam mat drying: Effect of whipping time and egg albumen concentration. *Journal of Food Processing and Preservation,* 42(2):e13467, 2018.

[44] Shittu, T. and Lawal, M., Factors affecting instant properties of powdered cocoa beverages. *Food Chemistry,* 100(1):91-98, 2007.

[45] Song, X.-D., Mujumdar, A.S., Law, C.-L., Fang, X.-M., Peng, W.-J., Deng, L.-Z., Wang, J., and Xiao, H.-W., Effect of drying air temperature on drying kinetics, color, carotenoid content, antioxidant capacity and oxidation of fat for lotus pollen. *Drying Technology,* 38(9):1151-1164, 2020.

[46] Thuwapanichayanan, R., Prachayawarakorn, S., and Soponronnarit, S., Effects of foaming agents and foam density on drying characteristics and textural property of banana foams. *LWT,* 47(2):348-357, 2012.

[47] Tulek, Y., Drying kinetics of oyster mushroom (*Pleurotus ostreatus*) in a convective hot air dryer. *Journal of Agricultural Science and Technology,* 13(5):655-664, 2011.

[48] Vasco, C., Avila, J., Ruales, J., Svanberg, U., and Kamal-Eldin, A., Physical and chemical characteristics of golden-yellow and purple-red varieties of tamarillo fruit (*Solanum betaceum* Cav.). *International Journal of Food Sciences and Nutrition,* 60(sup7):278-288, 2009.

[49] Vernon-Carter, E.J., Espinosa-Paredes, G., Beristain, C.I., and Romero-Tehuitzil, H., Effect of foaming agents on the stability, rheological properties, drying kinetics and flavour retention of tamarind foam-mats. *Food Research International,* 34(7):587-598, 2001.

[50] Völp, A.R., Seitz, J., and Willenbacher, N., Structure and rheology of foams stabilized by lupin protein isolate of *Lupinus. angustifolius*. *Food Hydrocolloids,* 120:106919, 2021.

[51] Zheng, X.-Z., Liu, C.-H., and Zhou, H., Optimization of parameters for microwave-assisted foam mat drying of blackcurrant pulp. *Drying Technology,* 29(2):230-238, 2011.