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Effects of Spray Drying Conditions of Microencapsulation of *Amaranthus gangeticus* Extract on Drying Behaviour

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Abstract

The aim of the study is to investigate the drying behaviour of spray-dried betacyanin pigment powder extracted from *Amaranthus gangeticus* as influenced by spray drying conditions which include inlet temperature, feed concentration and feed flow rate. β-cyclodextrin and maltodextrin were used as encapsulating agents. Central composite design was applied to model spray drying process with seventeen and thirteen formulations were conducted, respectively. Several parameters including feed moisture, powder moisture, drying ratio, productivity, surface tension, density and viscosity of feed were determined experimentally. The drying rate, droplet size and drying time of *A. gangeticus* extracted betacyanins were investigated during spray drying.

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Keywords: *Amaranthus gangeticus*; betacyanins; β-cyclodextrin; maltodextrin; central composite design; spray drying, drying rate; droplet size; drying time

1. Introduction

Betalains are one of the natural pigments found in nature. They are divided into two groups: red-violet betacyanins and yellow-orange betaxanthins. Betalains are mainly found in red beet, cactus pear and amaranth. The

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betalains from amaranth now are used as natural food colourant for alcoholic beverages in northwestern Argentina and Bolivia, as well as for maize dough in southwest United States and Mexico There are high amount of acylated betacyanins found in amaranth and due to the fact that they can be spray-dried for stabilization purpose (Socaciu, 2008). Encapsulation of betacyanin pigment can be achieved by transforming from liquid droplets into solid powder using encapsulating agents such as polysaccharides, proteins or lipids. Maltodextrin is one of the most common encapsulating agents applied due to its low viscosity, mild flavour, clear and highly soluble in water (Gibbs et al., 1999). Further, cyclodextrins are also widely used in pharmaceutical industries, which are produced by enzymatic hydrolysis of starch. The three-dimensional cyclic and toroidal structure allows substances to host and forms inclusion complexes. The outer part of cyclodextrins has more hydrophilic character than inner part (Castro et al., 2010).

The objectives of the study are to investigate the drying rate, drying time and droplet size of encapsulated betacyanins from *Amaranthus gangeticus* as affected by the studied factors which include inlet temperature, carrier concentration (maltodextrin and β-cyclodextrin concentration) and feed flow rate. Response surface methodology (RSM) is used as statistical tool to design experiments and analyze results.

2. Materials and methods

2.1. Raw materials

A batch of red amaranth (*Amaranthus gangeticus* species) which is also known as “bayam merah” in Malaysia, was purchased from Pasar Borong, Seri Kembangan, Selangor Darul Ehsan, Malaysia. Cleaning process was done by rinsing the vegetables with tap water to remove root and soil. After that they were stored in the freezer at -20 °C until being analyzed.

2.2. Betacyanin extraction and sample preparation for spray drying

Betacyanin extraction was accomplished by several processes: cutting, blanching, centrifugation, filtration and evaporation, described by Chong et al. (2013). The feed was composed of 10% of pigment extracts mixed with encapsulating agents (maltodextrin or β-cyclodextrin) and dispersed in distilled water. In case of preparation of the feed using β-cyclodextrin as encapsulating agent, it was heated up with constant stirring in order to solubilize β-cyclodextrin before the addition of pigment extracts. Homogenization was done using a homogenizer (WiseMix^{TM} Homogenizer HG15A, Malaysia) operated at 10^4 rpm for 5 minutes before delivering into a spray drier (SD-05 England). The inlet temperature, concentration of encapsulating agents and feed flow rate were operated based on experimental design. The encapsulated powders were then stored in a chiller until analyzed.

2.3. Experimental design

The experiments were designed using a statistical software (STATGRAPHICS Centurion XVI.I, USA) and were described by Chong et al. (2013). A central composite rotatable design was conducted and illustrated in Table 1. Two factors were considered for using maltodextrin as encapsulating agent: inlet temperature and maltodextrin concentration; whereas for β-cyclodextrin encapsulated pigment, the factor for feed flow rate was an included. The studied responses were drying rate, droplet size and drying time. Eq. 1 and 2 are the fitted model for maltodextrin-encapsulated and β-cyclodextrin-encapsulated pigment, respectively:

$$x = \theta_0 + \theta_1 T_1 + \theta_2 C_1 + \theta_{11} T_1^2 + \theta_{22} C_1^2 + \theta_{12} T_1 C_1 \quad (1)$$

where x is the response for maltodextrin-encapsulated pigment, θ_0 is the interception coefficient, θ_1 and θ_2 are linear terms, θ_{11} and θ_{22} are quadratic terms, θ_{12} is an interaction term, T_1 is the inlet temperature and C_1 is the maltodextrin concentration.

$$y = \theta_0 + \theta_1 T + \theta_2 C + \theta_3 F + \theta_{12} TC + \theta_{13} TF + \theta_{23} CF + \theta_{11} T^2 + \theta_{22} C^2 + \theta_{33} F^2 \quad (2)$$

where y is the response for β-cyclodextrin-encapsulated pigment, θ_0 is the interception coefficient, θ_1, θ_2 and θ_3 are linear terms, θ_{12}, θ_{13} and θ_{23} are the interaction terms, θ_{11} and θ_{22} and θ_{33} are quadratic terms, T is the inlet temperature, C is the β-cyclodextrin concentration and F is the feed flow rate.

Table 1. Variables and the levels for central composite rotatable design (CCRD).

Variable	Levels (maltodextrin)					Levels (β-cyclodextrin)				
	-1.414	-1	0	+1	+1.414	-1.68	-1	0	+1	+1.68
Inlet temperature (°C)	132	140	160	180	188	140	150	165	180	190
Concentration (%)	6	10	20	30	34	5	8	12	16	19
Feed flow rate (ml/min)	-	-	-	-	-	444	6	9	12	14

2.4. Drying ratio, productivity and drying rate

Drying performance was evaluated by measuring the drying ratio, productivity and drying rate. The drying ratio, productivity and drying rate were calculated according to the methods described by Cai and Corke (2000). The equations for drying ratio, productivity and drying rate are shown in Eq. 3, Eq. 4 and Eq. 5, respectively:

$$\text{Drying ratio} = \frac{X_f + 1}{X_p + 1} \quad (3)$$

where X_f is feed moisture, X_p is powder moisture. The moisture content was analyzed using a moisture analyzer (Ohaus MB45, USA).

$$\text{Productivity (g/hr)} = \frac{\text{Feed flow rate}}{\text{Drying ratio}} \quad (4)$$

$$\text{Drying rate (g/hr)} = \text{Feed flow rate} - \text{productivity} \quad (5)$$

2.5. Evaluation of droplet size

The Sauter diameter of the droplets d_p for two-fluid atomisers produced during spray drying was described by Richter (2004) and was calculated using Eq. 6:

$$\frac{d_p}{D} \approx 0.48\left(\frac{\sigma}{\rho_g \times D \times v_{rel}^{2}}\right)^{0.4}\left(1+\frac{1}{\eta}\right)^{0.4} + 0.15\left(\frac{\mu^2}{\sigma \times \rho_l \times D}\right)^{0.5}\left(1+\frac{1}{\eta}\right) \quad (6)$$

where D is nozzle diameter (fixed at 0.0005m), σ is air-water surface tension (N/m), ρ_g is density of gas (kg/m^3), v_{rel}^2 is gas-liquid relative velocity (fixed at 120 m/s), η is gas-liquid mass ratio, μ is viscosity of liquid (Pa s) and ρ_l is density of liquid (kg/m^3). The air-water surface tension was measured based on Tate's law. This was experimentally determined and was described by Lee et al. (2009) with slight modification. The feed was filled up in a 50 ml pipette tip and was allowed to drip in slow motion by gravitational force. The weight of the droplet was recorded. The calculation of air-water surface tension is shown in Eq. 7:

$$\sigma = \frac{mg}{2\pi r} \quad (7)$$

where m is mass of the falling droplet (m), g is the gravitational acceleration (m/s^2) and r is the radius of dripping tip (m).

The viscosity of the feed was measured using a rheometer (AR-G2 USA) with geometry of 60 mm cone. The range of shear rate was set between 0 and 100 1/s.

2.6. Evaluation of drying time

The measurement of drying time for a pure liquid drop falling freely in air was described by Marshall (1954). The equation was simplified and suitable for drop less than 100 μm shown in Eq. 8:

$$t = \frac{\rho_l \lambda \left(d_0^{\,2} - d_t^{\,2}\right)}{8 \times k_f \times \Delta T} \tag{8}$$

where ρ_l is density of liquid (kg/m^3), λ is latent heat of vapourisation (J/kg), d_0 is initial diameter of drop (m), d_t is diameter of evaporating drop at time t (m), k_f is thermal conductivity (W/m°C) and ΔT is temperature difference between heated air temperature and wet bulb temperature for heated air (°C).

3. Results and discussion

3.1. Analysis of response surfaces

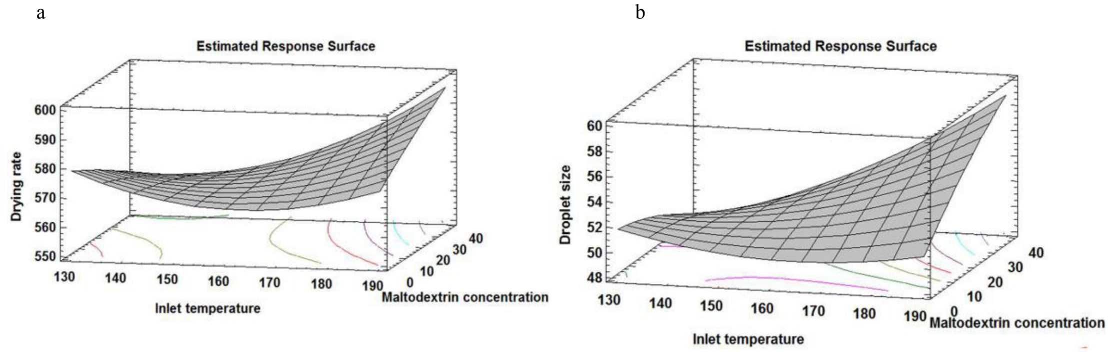
The response surface graphs of maltodextrin-encapsulated pigment for drying rate, droplet size and drying time as affected by inlet temperature and maltodextrin concentration are presented in Fig. 1, whereas Fig. 2, 3 and 4 illustrate the response surface graphs of β-cyclodextrin-encapsulated pigment for the three responses studied as affected by three factors: inlet temperature, β-cyclodextrin concentration and feed flow rate. A quadratic model was studied for all the response models and analysis of variance (ANOVA) was used to indicate significant differences. The regression coefficients and R^2 of both pigments for every response are shown in Table 2. Low R^2 values (< 0.73) were found in Table 2 for both pigments. The lack of fit test did not show significant differences ($P > 0.05$) among all the responses, which indicated that the models are adequate to describe the experimental data. However there was a significant difference ($P < 0.05$) for lack of fit found for the droplet size of maltodextrin-encapsulated pigment.

Table 2. Coefficient values and R^2 of proposed models.

	R	θ_0	θ_1	θ_2	θ_3	θ_{11}	θ_{12}	θ_{13}	θ_{22}	θ_{23}	θ_{33}	R^2
MDEP	DR	851.88	-3.5	-2.27	-	0.01	0.02	-	-	-	-	0.348
	DS	91	-0.5	-0.68	-	-	-	-	-	-	-	0.385
	DT	6.54	-0.04	-0.19	-	-	-	-	-	-	-	0.186
BCDEP	DR	8291.52	-93.24	73.85	-144.54	0.31	-0.97	0.3	4.04	-0.97	6.96	0.416
	DS	60.93	-0.15	0.45	-2.46	-	-	0.01	0.03	-0.041	0.08	0.732
	DT	-11.7	0.16	0.03	-0.13	-	-	-	-	-	-	0.385

MDEP = Maltodexrein-encapsulated pigment, BCDEP = β-cyclodextrin-encapsulated pigment, R = Responses, DR = Drying rate, DS = Droplet size, DT = Drying time

A significant difference ($P < 0.05$) was found in droplet size in linear term of the inlet temperature for the maltodextrin-encapsulated pigment. Yet, there were no significant differences ($P > 0.05$) observed for drying rate and drying time. For β-cyclodextrin-encapsulated pigment, the linear term of the inlet temperature and β-cyclodextrin concentration, and the quadratic term of feed flow rate significantly ($P < 0.05$) affected droplet size. No remarkable changes ($P > 0.05$) were found for the responses drying rate and drying time.



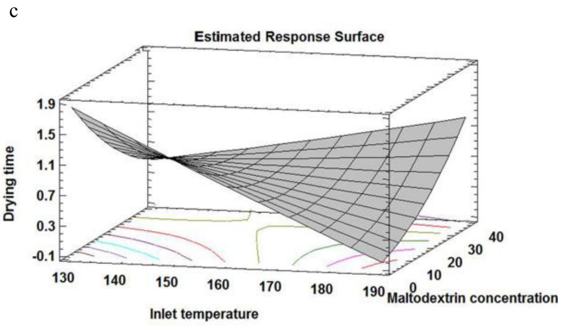


Fig. 1. Response surface plot for (a) drying rate, (b) droplet size and (c) drying time as affected by inlet temperature and maltodextrin concentration.

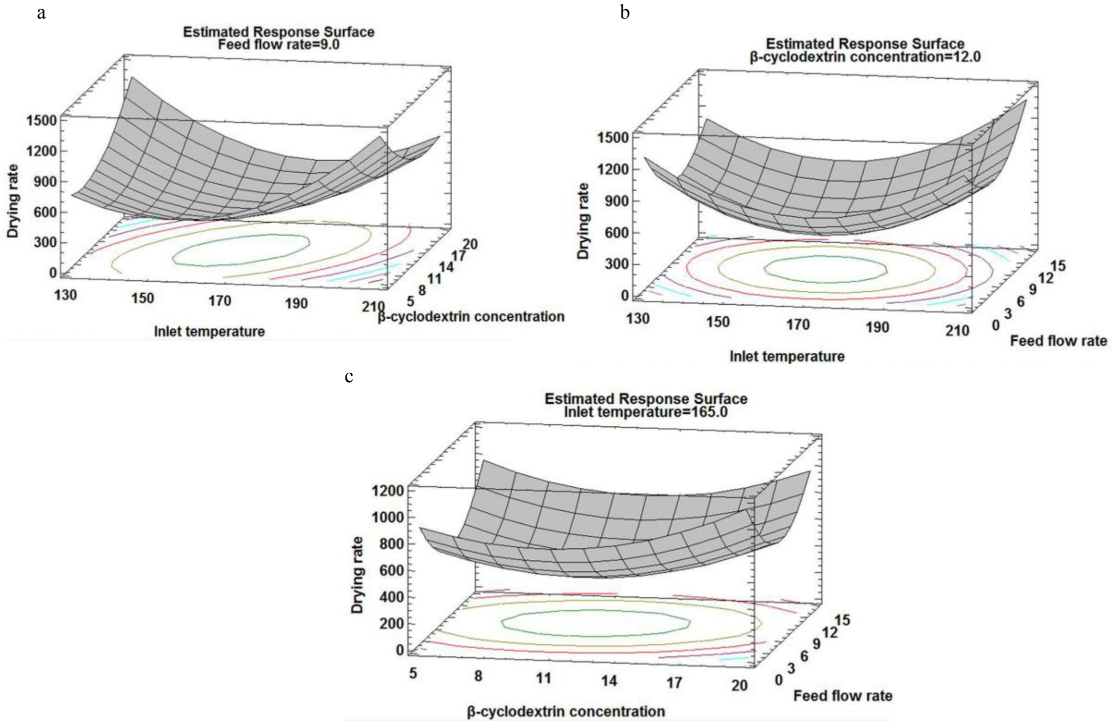
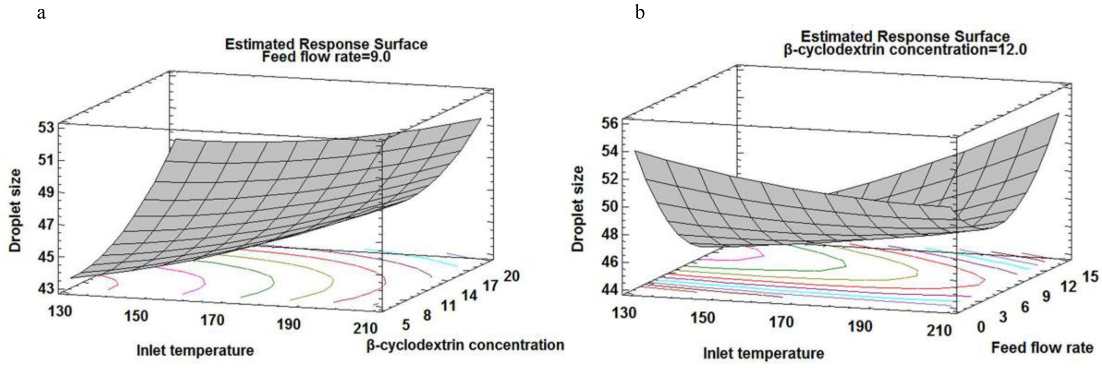


Fig. 2. Response surface plot for drying rate for (a) 9 ml/min feed flow rate, (b) 12% β-cyclodextrin concentration and (c) 165 °C inlet temperature.



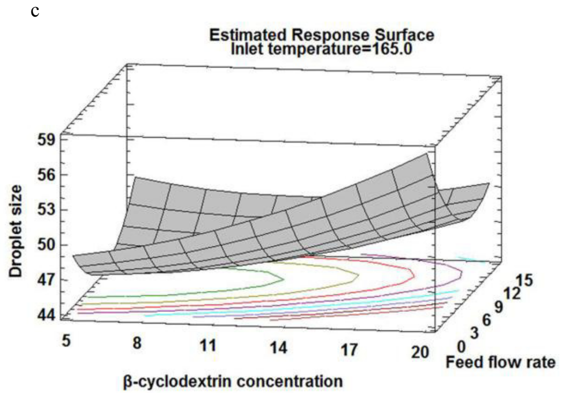


Fig. 3. Response surface plot for droplet size for (a) 9 ml/min feed flow rate, (b) 12% β-cyclodextrin concentration and (c) 165 °C inlet temperature.

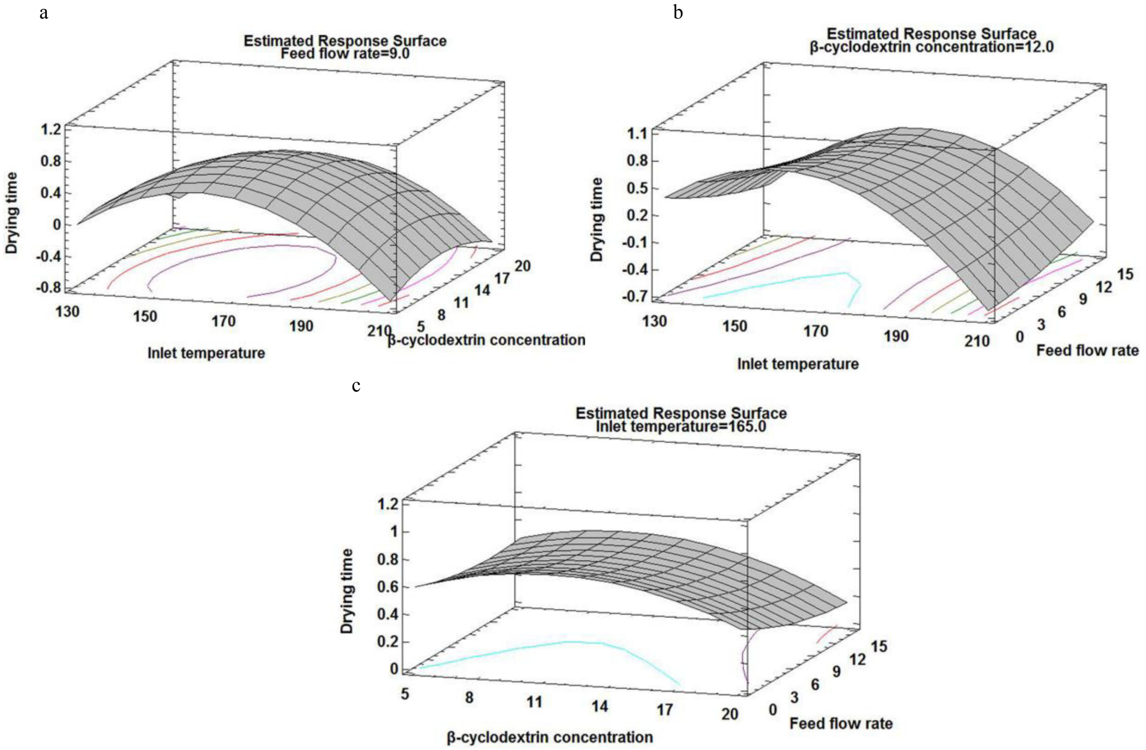


Fig. 4. Response surface plot for drying time for (a) 9 ml/min feed flow rate, (b) 12% β-cyclodextrin concentration and (c) 165 °C inlet temperature.

3.2. Drying rate

Tables 3 and 4 describe the drying ratio, productivity and drying rate of maltodextrin-encapsulated and β-cyclodextrin-encapsulated pigment, respectively. The productivity of powder is important to reduce the production cost. Higher productivity of maltodextrin-encapsulated pigment was obtained with an increase of maltodextrin concentration at a similar inlet temperature, shown in Table 3. This is in an agreement with Cai and Corke (2000). Increasing the maltodextrin concentration resulted in a higher feed solid content and thus high productivity was obtained. For the β-cyclodextrin-encapsulated pigment as shown in Table 4, the highest value of productivity

(122.59) was noticed at inlet temperature 165 °C, β-cyclodextrin 12% and feed flow rate 944 g/hr. This was due to the low drying ratio obtained that caused higher productivity when higher feed flow rate was applied.

The drying rate during spray drying can affect the physical properties of powder produced such as moisture content, bulk density and particle size. Theoretically, a high inlet temperature would result in a faster drying rate. Although the inlet temperature did not obviously affect the drying rate in this research, there was an increasing trend in drying rate when the inlet temperature increased for the high maltodextrin concentration for the maltodextrin-encapsulated pigment shown in Fig. 1(a). In addition, a higher drying rate was also observed when an increasing maltodextrin concentration was used with a higher inlet temperature. The fastest drying rate for β-cyclodextrin-encapsulated pigment was 821.23 g/hr as shown in Table 4. When the β-cyclodextrin concentration and feed flow rate was fixed to 12% and 607 g/hr, respectively, an increasing inlet temperature caused an increase in drying rate.

3.3. Droplet size

The droplet size during spray drying can be affected by properties of the liquid droplets and the drying air. The parameters were experimentally obtained and tabulated in Table 5 and Table 6. Generally the high viscosity of the liquid restrained the formation of natural instability in the liquid jet and reduced the Reynolds number that resulted in a larger droplet size. The high surface tension of the liquid also produced a larger droplet size (Chen and Mujumdar, 2008). The range of droplet size for the maltodextrin-encapsulated pigment was from 48.98 to 58.39 µm presented in Table 5. A similar pattern of response surface graph for the droplet size (Fig. 1(b)) was found in comparison with the response surface graph for drying rate (Fig. 1(a)). As shown in Fig. 1(b), an obvious rise in droplet size was noticed at a high maltodextrin concentration with increasing inlet temperature. This could be explained that a high inlet temperature produced a faster drying rate which restricted the shrinkage behaviour of the droplets during the spray drying process, hence larger droplet sizes were produced (Reiniccius, 2001). Although the maltodextrin concentration did not significantly influence droplet size for the maltodextrin-encapsulated pigment, an increase in the maltodextrin concentration led to larger droplet size for a high inlet temperature displayed in Figure 1(b). This was probably due to the high level of maltodextrin concentration increased the viscosity of the liquid (Masters, 1991).

The droplet sizes of β-cyclodextrin-encapsulated pigment are tabulated in Table 6 in a range between 44.44 and 49.44 µm, having a lower and shorter range compared to the maltodextrin-encapsulated pigment. The droplet size was greatly affected by inlet temperature and β-cyclodextrin concentration as illustrated in Fig. 2(a). Increasing both factors caused an increase in the droplet size. A larger droplet size was generated by increasing the feed flow rate during spray drying (Maury et al., 2005). As shown in Fig. 3(b), it was found that the feed flow rate had a positive effect on droplet size at a higher inlet temperature.

Table 3. Effect of inlet temperature and maltodextrin concentration on drying ratio, productivity and drying rate of betacyanin pigment powder.

Inlet temperature (°C)	Maltodextrin concentration (%)	Feed flow rate (g/hr)	Drying ratio	Productivity	Drying rate (g/hr)
160	34	640	12.2	53	588
160	20	621	12.3	51	571
160	20	621	13.3	47	574
160	20	621	13.7	45	576
180	10	599	13.9	43	556
160	20	621	14.3	43	578
188	20	621	15.1	41	580
160	6	595	15.2	39	566
132	20	621	11.3	55	566
180	30	628	13.9	45	583
140	30	599	10.7	59	569
140	10	621	15.1	40	559
160	20	620	11.6	53	568

Table 4. Effect of inlet temperature, β-cyclodextrin concentration and feed rate on drying ratio, productivity and drying rate of betacyanin pigment powder.

Inlet temprature (°C)	β-cyclodextrin concentration (%)	Feed flow rate (g/hr)	Drying ratio	Productivity	Drying rate (g/hr)
165	12	270	20.1	13	256
165	5	593	12.0	50	544
190	12	607	13.6	45	562
165	12	944	7.7	123	821
165	12	607	9.2	66	540
150	16	828	7.2	115	713
150	8	800	9.4	85	715
180	8	800	9.3	86	714
150	16	409	12.5	33	376
165	19	628	8.3	76	552
180	16	409	14.5	28	381
180	16	818	8.8	93	725
150	8	391	14.7	27	365
165	12	607	10.2	60	547
180	8	400	14.7	27	373
165	12	607	8.2	74	532
140	12	607	7.9	76	530

3.4. Drying time

The drying time of maltodextrin-encapsulated and β-cyclodextrin-encapsulated pigment are tabulated in Tables 7 and 8 with the experimental parameters, respectively. The drying time for spray drying was achieved in a few seconds due to the large surface area of the liquid droplets exposed to hot air. A range from 0.31 to 1.73 seconds of drying time was observed in Table 7 for the maltodextrin-encapsulated pigment. Figure 1(c) represents the response surface graph of the drying time and it was found that the drying time was proportional to the maltodextrin concentration and inversely proportional to the inlet temperature. For β-cyclodextrin-encapsulated pigment, the range of drying time was shorter than for the maltodextrin-encapsulated pigment, which was in the range between 0.24 and 1.08 seconds as shown in Table 8. There was an obvious reduction in drying time with increasing of inlet temperature in Fig. 4(a). A higher inlet temperature exhibited a faster drying rate and reduced the drying time needed during spray drying. Although the β-cyclodextrin concentration did not affect the drying time, increasing maltodextrin concentration for the maltodextrin-encapsulated pigment at a high inlet temperature led to a higher viscosity that could possibly prolong the drying time. Truong et al. (2005) pointed out that the drying process was shorten with droplet size of less than 70 μm, which made the drying time less than one second.

Table 5. Values of droplet size of maltodextrin-encapsulated betacyanin pigment powder with the experimental parameters.

IT (°C)	MD (%)	σ (N/m)	μ (mPaS)	ρ_l (kg/m^3)	ρ_g(kg/m^3)	D (m)	V_{rel} (m/s)	η	d_p(μm)
160	34.14	0.0770	18.140	1068	1.609	0.0005	120	0.865	58.39
160	20.00	0.0940	5.221	1035	1.609	0.0005	120	0.892	51.03
160	20.00	0.0939	5.346	1035	1.609	0.0005	120	0.892	51.10
160	20.00	0.0939	5.526	1035	1.609	0.0005	120	0.892	51.23
180	10.00	0.0993	2.754	998	1.538	0.0005	120	0.925	50.75
160	20.00	0.0936	5.366	1035	1.609	0.0005	120	0.892	51.06
188	20.00	0.0942	5.346	1035	1.511	0.0005	120	0.892	52.36
160	5.86	0.1013	1.708	992	1.609	0.0005	120	0.932	49.44
132	20.00	0.0933	5.346	1035	1.720	0.0005	120	0.892	49.75
180	30.00	0.0875	11.440	1047	1.538	0.0005	120	0.882	55.43
140	30.00	0.0870	11.440	1047	1.687	0.0005	120	0.882	53.65
140	10.00	0.0993	2.754	998	1.687	0.0005	120	0.925	48.98
160	20.00	0.0930	5.448	1035	1.609	0.0005	120	0.892	51.01

IT = Inlet temperature, MD = Maltodextrin concentration, σ = air-water surface tension, μ = viscosity of liquid, ρ_l = density of liquid, ρ_g = density of gas, D = nozzle diameter, V_{rel}=gas-liquid relative velocity, η = gas-liquid mass ratio, d_p = droplet size

Table 6. Values of droplet size of β-cyclodextrin-encapsulated betacyanin pigment powder with the experimental parameters.

IT (°C)	BC (%)	FFR (ml/min)	σ (N/m)	μ (mPaS)	ρ_l (kg/m^3)	ρ_g(kg/m^3)	D (m)	V_{rel} (m/s)	η	d_p(μm)
165	12.0	4	0.0847	0.9670	1044	1.591	0.0005	120	0.887	46.33
165	5.27	9	0.1005	0.7013	988	1.591	0.0005	120	0.878	49.44
190	12.0	9	0.0847	0.9679	1044	1.505	0.0005	120	0.841	47.91
165	12.0	14	0.0840	0.9673	1044	1.591	0.0005	120	0.841	46.73
165	12.0	9	0.0851	0.9666	1044	1.591	0.0005	120	0.832	47.08
150	16.0	12	0.0750	1.2400	1060	1.647	0.0005	120	0.822	44.58
150	8.0	12	0.0935	0.8529	1041	1.647	0.0005	120	0.841	47.95
180	8.0	12	0.0935	0.8535	1041	1.538	0.0005	120	0.832	49.39
150	16.0	6	0.0751	1.2450	1060	1.647	0.0005	120	0.813	44.71
165	18.73	9	0.0695	1.4890	1093	1.591	0.0005	120	0.795	44.44
180	16.0	6	0.0759	1.2400	1060	1.538	0.0005	120	0.841	45.76
180	16.0	12	0.0745	1.2330	1060	1.538	0.0005	120	0.832	45.54
150	8.0	6	0.0931	0.8525	1041	1.647	0.0005	120	0.850	47.76
165	12.0	9	0.0847	0.9680	1044	1.591	0.0005	120	0.841	46.88
180	8.0	6	0.0935	0.8511	1041	1.538	0.0005	120	0.850	49.15
165	12.0	9	0.0858	0.9673	1044	1.591	0.0005	120	0.822	47.35
140	12.0	9	0.0844	0.9682	1044	1.687	0.0005	120	0.841	45.74

BC = Beta-cyclodextrin voncentration, FFR = feed rate

Table 7. Values of drying time of maltodextrin-encapsulated betacyanin pigment during spray drying with the experimental parameters.

IT (°C)	MD (%)	ρ_l (kg/m^3)	λ (J/kg)	d_o (m)	d_t (m)	k_f (W/m°C)	ΔT (°C)	t (s)
160	34.14	1068	2.20×10^6	5.84×10^{-5}	7.63×10^{-6}	0.0344	40	0.72
160	20.00	1035	2.20×10^6	5.10×10^{-5}	5.85×10^{-6}	0.0344	40	0.53
160	20.00	1035	2.20×10^6	5.11×10^{-5}	7.46×10^{-6}	0.0344	40	0.53
160	20.00	1035	2.20×10^6	5.12×10^{-5}	1.11×10^{-5}	0.0344	40	0.52
180	10.00	998	2.20×10^6	5.08×10^{-5}	9.34×10^{-6}	0.0357	60	0.32
160	20.00	1035	2.20×10^6	5.11×10^{-5}	7.88×10^{-6}	0.0344	41	0.51
188	20.00	1035	2.20×10^6	5.24×10^{-5}	6.09×10^{-6}	0.0364	68	0.31
160	5.86	992	2.20×10^6	4.94×10^{-5}	1.03×10^{-5}	0.0344	41	0.45
132	20.00	1035	2.20×10^6	4.98×10^{-5}	8.62×10^{-6}	0.0329	12	1.73
180	30.00	1047	2.20×10^6	5.54×10^{-5}	9.21×10^{-6}	0.0357	60	0.40
140	30.00	1047	2.19×10^6	5.37×10^{-5}	6.85×10^{-6}	0.0333	16	1.52
140	10.00	998	2.19×10^6	4.90×10^{-5}	7.85×10^{-6}	0.0333	16	1.20
160	20.00	1035	2.20×10^6	5.10×10^{-5}	9.48×10^{-6}	0.0344	40	0.52

ρ_l = density of liquid, λ = latent heat of vapourization, d_o = Initial diameter of drop, d_t = Diameter of evaporating drop at time t, k_f = thermal conductivity, ΔT = Temperature difference between heated air temperature and wet bulb temperature for heated air, t = drying time

Table 8. Values of drying time of β-encapsulated betacyanin pigment during spray drying with the experimental parameters

IT (°C)	BC (%)	FFR (ml/min)	ρ_l (kg/m^3)	λ (J/kg)	d_o (m)	d_t (m)	k_f (W/m°C)	ΔT (°C)	t (s)
165	12.0	4	1044	2.20×10^6	4.63×10^{-5}	7.28×10^{-6}	0.0350	45	0.38
165	5.27	9	988	2.20×10^6	4.94×10^{-5}	6.09×10^{-6}	0.0350	45	0.42
190	12.0	9	1044	2.20×10^6	4.79×10^{-5}	1.09×10^{-5}	0.0365	70	0.24
165	12.0	14	1044	2.20×10^6	4.67×10^{-5}	8.69×10^{-6}	0.0350	45	0.39
165	12.0	9	1044	2.20×10^6	4.71×10^{-5}	1.03×10^{-5}	0.0350	45	0.39
150	16.0	12	1060	2.20×10^6	4.46×10^{-5}	1.10×10^{-5}	0.0336	30	0.54
150	8.0	12	1041	2.20×10^6	4.80×10^{-5}	7.16×10^{-6}	0.0336	30	0.64
180	8.0	12	1041	2.20×10^6	4.94×10^{-5}	8.91×10^{-6}	0.0357	60	0.31
150	16.0	6	1060	2.20×10^6	4.47×10^{-5}	7.37×10^{-6}	0.0336	30	0.56
165	18.73	9	1093	2.20×10^6	4.44×10^{-5}	1.40×10^{-5}	0.0350	45	0.34
180	16.0	6	1060	2.20×10^6	4.58×10^{-5}	9.08×10^{-6}	0.0357	60	0.27
180	16.0	12	1060	2.20×10^6	4.55×10^{-5}	1.14×10^{-5}	0.0357	60	0.26
150	8.0	6	1041	2.20×10^6	4.78×10^{-5}	6.53×10^{-6}	0.0336	30	0.63
165	12.0	9	1044	2.20×10^6	4.69×10^{-5}	1.11×10^{-5}	0.0350	45	0.38
180	8.0	6	1041	2.20×10^6	4.92×10^{-5}	6.73×10^{-6}	0.0357	60	0.32
165	12.0	9	1044	2.20×10^6	4.74×10^{-5}	9.51×10^{-6}	0.0350	45	0.39
140	12.0	9	1044	2.19×10^6	4.57×10^{-5}	9.51×10^{-6}	0.0333	16	1.08

4. Conclusions

The droplet size of the maltodextrin-encapsulated and β-cyclodextrin betacyanin pigment was significantly and positively influenced by inlet temperature with a linear effect. For the β-cyclodextrin-encapsulated pigment, the β-cyclodextrin concentration also had a positive impact on droplet size with a linear effect. A quadratic effect was found for the factor feed flow rate on droplet size for the β-cyclodextrin-encapsulated betacyanin pigment. The studied factors insignificantly influenced the drying rate for both pigments. However a conditionally higher drying rate was observed at a high inlet temperature. Although no significant effect was found for the response drying time for both pigments, there was a positive relationship for the maltodextrin and β-cyclodextrin concentration, and a negative impact for the inlet temperature. In comparison with the maltodextrin-encapsulated pigment, the β-cyclodextrin-encapsulated pigment had shorter range of droplet size and drying time during spray drying.

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