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Original research

Effect of spray drying conditions and feed composition on the physical properties of barerry (*Berberis vulgaris*) juice powder

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A B S T R A C T

In this study, the effect of some processing parameters on bulk density, particle density, particle size and some of powder reconstruction properties such as dispersibility, Wettability and water solubility index of spray dried barberry (*Berberis vulgaris*) juice powders were investigated. A Pilot Spray Dryer (Two- Flow nozzle, counter-current, one cyclone) was employed for the spray drying process. Independent variables were inlet air temperature (T; 160, 175 and 190℃), feed flow rate (Q; 34, 36 and 38 ml/min) and dry matter weight ratio of maltodextrin and the dry matter weight of barberry juice (MD/FJ; 1.1, 1.2 and 1.3) upon the physical properties (bulk density, particle density, particle size, water solubility index, dispersibility and Wettability) of powder were observed. Analysis of experimental data i.e., Barberry powder properties and process parameters at best quality (bulk density 1.47, particle density1.06, particle size 499.48, water solubility index 89.76, dispersability 56.22 and Wettability 71.46) of powder at inlet air temperature (T=181℃), feed flow rate (Q= 38ml/min), ratio of maltodextrin and the dry matter weight of barberry juice (MD/FJ= 1.13).

Keywords: Spray dryer, Barberry juice, Inlet air temperature, Feed flow rate, Bulk density, Particle size

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1. Introduction

Iran ranks first in Barberry production and contribute 94% of total this fruit production in the world (Chaji et al., 2008). Seedless barberry [*Berberis vulgaris* (L.) var. *asperma*] is member of family *Berberidaceae* (Tehranifar, 2002). It has been widely used as a food additive. In Iran, more than 10,000 tonnes of barberries are produced each year. Southern Khorasan, located at the Iran, is the production center with about 97.8 of growing field of barberry. Production is approximately 93% of the world's Barberry. According to evidence the cultivation of seedless barberry in south of province backs to two hundred years ago. The paper summarized detailed information about cultivation, taxonomy, propagation, utilization, and processing of seedless barberry cultivated in the southern parts of Khorasan, Iran. Barberry is one of the province's strategic products that play important role in the life economic of the region and employment. Barberry is a seasonal product and it cannot be used fresh at all year round. (Chaji et al., 2008).

The main disadvantage of cost and slow process that increases the risk of product damage caused by fall rains and pollution in all types of mold, yeast and wasted about 30% to 35% of annually product, intended results. One way to reduce waste this valuable product, using industrial drying and mechanized equipment that will dramatically reduce pollution and waste it (Chaji et al., 2008).

Application of spray drying for dehydrating barberry is not in vogue in Iran. Spray drying is one of the techniques most utilized in the food industry and under optimal processing conditions, it has proved to be an effective method to obtain dehydrated finished product of good quality. Fruit juice spray drying has great economic potential. Packing and transportation cost is reduced due to the spray drying of fruit juice or pulp and also increases the shelf life of dried product, so that it can be used in off season of fruit availability. Therefore, the present study is aimed at the development of suitable

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process for the product of barberry powder by using a laboratory model spray dryer and then achieving industrial production of it.

2. Material and Methods

2.1. Material

Barberry juice concentrated with Brix (60-70) was purchased from the Kesht-o-sanat khooshe sorkh factory is located in the Ghaen city of Iran. Samples were stored at -18℃ in a freezer until use. Maltodextrin (Yazd Mahshad Company of Iran) with 18-20 dextrose equivalents (DE) was used in the experiments.

2.2. Sample Preparation

By adding water to the concentrate, barberry juice was prepared with 20.5 Brix. Then added different amounts of maltodextrin. Samples before injection into Pilot Spray Dryer (Two- Flow nozzle, counter- current, one cyclone) homogenized with the mixer (Gosonic-GHM818-200W, China) with150 rpm speed, were filtered before injection with the fabrics. After preliminary examination dry matter weight ratio of maltodextrin and the dry matter weight of barberry juice (MD/FJ, 1.1, 1.2 and 1.3), inlet temperature (T,160, 175 and 190℃) and feed rate (Q, 34, 36 and 38 ml/min) were selected.

2.3. Spray Drying Process

A Pilot spray dryer made in Soroush Company of Iran was used in the process, which was mainly supplied with control panel, electric resistance heater, peristaltic pump, two fluid nozzle, drying chamber, and cyclone. Ambient air was heated by an electric resistance heater and the heated air was blown in counter- current of the spray liquid through the draying chamber. The inlet and outlet air temperature was measured and the mixture was fed through a pump to the fluid nozzle where it was atomized and sprayed in to the drying chamber. Thus, the barberry powder and dust were separate in the cyclone separator. All the spray- dried barberry powders were collected weight, sealed in a glass bottle, and stored at 4℃.

2.4. Experimental Design

Weight ratio of maltodextrin and the dry matter weight of barberry juice (MD/FJ), inlet temperature (T) and feed flow rate (Q) were selected as the independent variables based on the preliminary study results. Response surface methodology (RSM) was used for modeling and analyzing of the optimization process. The experimental design employed in the experiment was a Quadratic design which consisted of 17 runs with 3 replicates of the central point for the estimation of pure error. The response variables (Y_n) bulk density (Y_1), particle density (Y_2), particle size (Y_3), water solubility index (Y_4), dispersability (Y_5), and wettability (Y_6).

2.5. Statistical Analysis

As for optimization of spray-drying process, the responses were analyzed using Design Expert software (version 7.0.0, Stat-Ease Inc., MN, 5413). In this study Central Composite Rotatable Design (CCRD). A second-order polynomial regression model was assumed for predicting all Y responses ($Y_1 - Y_6$) which could be expressed by the following equation (Eq. 1):

$$Y = A_0 + A_1X_1 + A_2X_2 + A_3X_3 + A_{11}X_1^2 + A_{22}X_2^2 + A_{33}X_3^2 + A_{12}X_1X_2 + A_{13}X_1X_3 + A_{23}X_2X_3 \quad \text{(Eq. 1)}$$

where A_0 was a constant; A_1, A_2, and A_{12}, A_{13}, A_{23} were cross-product coefficients; and A_{11}, A_{22}, A_{33} were quadratic coefficients. The fitness of the model was evaluated by the coefficient of determination R2 and the analysis of variance (ANOVA, F-test). The effects of the independent variables were displayed in response surfaces perturbation plots. All samples were treated and analyzed in triplicate. A value of $p<0.05$ was considered as statistically significant.

2.6. Bulk density

A known quantity of spray-dried barberry juice powder was loaded into a 10mL graduated cylinder and the volume occupied was recorded and then used to calculate the bulk density (weight per volume) (Jangam & Thorat., 2010).

2.7. Particle density

The particle densities of the powders were calculated by adopting the pycnometer method. An amount of 2.5 ± 0.04 g of each treatment was placed in an empty liquid pycnometer (25 mL) and filled with a measured volume of ether 2 petroleum. Particle density is the total particle weight divided by its total volume. Ether 2 petroleum was used because of its ability to penetrate the finest external pores connected to the surface of the material without dissolving the material (Fernandes et al., 2013).

2.8. Particle size

The particle size of all the powder samples was measured by using a particle size analyzer (Malvern Instruments, Malvern nano size ZS, UK). Reconstituted powder was placed into the particle size analyzer and the data acquisition was recorded automatically (Tonon et al., 2010). The mean particle size of the powder was recorded and was reported in micro meters (µm).

2.9. Water solubility index

Water solubility index (WSI) was determined using the method described by Gomez (1984). A total of 2.5 g of dry powders were added to 30 mL of water at 30℃ in a 50 mL centrifuge tube, stirred intermittently for 30min and then centrifuged by (Hewtich model EBA 20) for 10 min at 5100 rpm. The supernatant was carefully poured off into a petri dish and oven-dried overnight. The amount of solid in the dried supernatant as a percentage of the total dry solids in the original 2.5 g sample gave an indication of the WSI. Wet solid remaining after centrifugation was dried in an oven (partsazane ariya model SH-206) overnight. WAI was calculated as the weight of dry solid divided by the amount of dry sample.

2.10. Dispersibility

Dispersibility measurements were performed according to the procedure described by Jinapong et al. (2008). A total of 10 mL distilled water at 25℃ was poured into a 50 mL beaker. 1 g powder was added into the beaker. The stopwatch was started and the sample was stirred vigorously for 15 s making 25 complete movements back and forth across the whole diameter of the beaker. The reconstituted powder was poured through a sieve (212 µm). The sieved powder was transferred to a weighed and dried aluminum pan and dried for 4 h in a hot air oven (partsazane ariya model SH-206) at 105℃. The dispersibility of the powder was calculated as follows (Eq. 2):

$$\text{Dispersibility}(\%) = \frac{(10+a)\times\%\text{TS}}{a\times\frac{100-b}{100}} \quad \text{(Eq. 2)}$$

where a =amount of powder (g) being used, b=moisture content in the powder, and %TS=dry matter in percentage in the reconstituted powder after it has been passed through the sieve.

2.11. Wettability

The wettability was evaluated according to the method described by Vissotto et al. (2010)., considering the time required for 1 g of powder deposited on the liquid surface to become completely submersed in 400 mL of distilled water at 25℃.

3. Results and Discussion

In the present study, effects of independent factors (MD/FJ, T, and Q) on the responses in spray drying process were analyzed by RSM and perturbation plot. The design layout and responses for each experiment are shown in table 1.

3.1. Influence of variables on the bulk density of barberry juice powder

The best way of visually expressing the effect of variables on the responses within the experimental space under investigation was to generate response surface plots of the model (Ferrari et al., 2012). Response surfaces for the effects of variables on the bulk density of barberry juice powder were shown in Fig. 1a–c. The trend of bulk density changes as one factor moved from the design range with the other factor held constant at the reference value was shown by the perturbation plot (Fig. 1d). In the present study, the reference point was set at the middle of the design space (Tc= 175℃, Qc= 36ml/min and MD/FJC= 1.2).

The effect of inlet temperature on bulk density is depicted in Fig. 1 and table 1, as can be seen inlet temperature opposite effect on bulk density of barberry juice powder. The lowest density was seen at highest an inlet temperature (190℃) and the highest density was shown at lowest an inlet temperature (160℃).

This in Figures1b, c and d, has similarly been confirmed. this is agreement with the results Tonon et al. (2008), based on studied the effect of inlet temperature(140, 170, 200℃) on the bulk density of acai juice powder and found that the increased temperature caused the reduction in bulk density. An increase in the inlet air temperature often results in a rapid formation of dried layer on the droplet surface and particle size and it causes the skinning over or casehardening on the droplets at the higher temperatures. This leads to the formation of vapor-impermeable films on the droplet surface, followed by the formation of vapor bubbles and, consequently the droplet expansion (Chegini and Ghobadian, 2005; Tonon et al., 2008). Walton (2000) reported, the increase of drying air temperature generally causes the decrease in bulk, particle density and provides the greater tendency to the particles to hollow. However Jamun juice powder produced at different inlet temperatures showed non-significant difference in bulk density. The highest bulk density was shown at an inlet temperature of 155℃, whereas the lowest bulk density was shown by sample C (0.24 g/mL) at an inlet temperature of 150℃. The feed flow rate (Q) was positively affected the bulk density in the barberry juice powder. Higher Q reduced the residence time between droplets and drying air, leading to less efficient heat transfer (Kurozawa et al., 2009). This resulted in higher bulk density of barberry juice powder. Additionally, these results were consistent with those reported by Ferrari et al. (2012), Moreira et al. (2009), and Kha et al. (2010). At constant atomizer speed, increasing the feed flow rate, more liquid was atomized into chamber, thus time of drying was reduced and finally the drying was incorrect (Phisut, 2012).

Table 1. Central composite rotate design and experiment data

Run	Variables* (original and coded value)			Responses**					
	X1(℃)	X2(ml/min)	(X3)	Y1(g/cm3)	Y2(µm)	Y3(%)	Y4(%)	Y5(%)	Y6(%)
1	190(+1)	34(-1)	1.1(-1)	1.425	0.9172	3139	93.68	62.0	100.0
2	160(-1)	34(-1)	1.1(-1)	1.442	0.920	2500	93.72	32.3	100.0
3	175(0)	36(0)	1.2(0)	1.426	1.0322	14490	93.76	50.0	88.0
4	175(0)	36(0)	1.2(0)	1.426	1.0322	14490	93.76	50.0	88.0
5	175(0)	36(0)	1.2(0)	1.426	1.0322	14490	93.76	50.0	88.0
6	190(+1)	38(+1)	1.1(-1)	1.497	1.0317	14490	90.20	57.78	89.0
7	190(+1)	38(+1)	1.3(+1)	1.438	1.2000	2000	93.72	57.36	59.0
8	160(-1)	34(-1)	1.3(+1)	1.411	1.098	8500	97.24	44.30	67.0
9	190(+1)	34(-1)	1.3(+1)	1.478	1.07	22585	100.00	54.24	79.0
10	160(-1)	38(+1)	1.1(-1)	1.471	1.033	500	96.84	41.10	76.0
11	175(0)	36(0)	1.2(0)	1.426	1.0322	14490	93.76	50.0	88.0
12	160(-1)	38(+1)	1.3(+1)	1.510	1.146	6500	90.36	53.10	57.28

*X_1 Inlet air temperature, X_2 Feed flow rate, X_3 MD/FJ,
**Y_1 Bulk density, Y_2 Particle density, Y_3 Particle size, Y_4 Water solubility index, Y_5 Dispersability, and Y_6 Wettability

The effect of ratio MD/FJ was negatively until central point and was positively after that. This was showed at fingers-1 (a,c and d). Goula and Adamopoulos (2008) studied the effect of maltodextrin addition (maltodextrin 6DE, 12DE, 21DE) on the properties of tomato powder. The result showed that the higher the maltodextrin dextrose equivalent (DE) causes higher the moisture content in the powder. This probably due to the chemical structure of high-DE maltodextrins, which have a high number of ramifications with hydrophilic groups, and thus can easily bind to water molecules from the ambient air during powder handling after the spray drying. Additionally, higher maltodextrin DE caused the increase in bulk density in the powder due to its stickiness.

The highest tapped density was shown by sample MD/FJ=1.3 at an inlet temperature of 160℃, The lower the bulk density, the more occluded air within the powders and, therefore, a greater possibility for product oxidation and reduced storage stability. Lower bulk density also implies greater volume for packaging (Lewis, 1987). With lower moisture contents, barberry juice powder was found to be more compact. This occurs mainly with higher inlet temperature and lower feed. Eq. (3) as follows:

$$Y_1 = 1.42 - 0.012X_1 + 0.015X_2 - 0.002X_3 + 0.006X_1^2 + 0.009X_2^2 + 0.19X_3^2 - 0.012X_1X_2 - 0.002X_1X_3 - 0.005X_2X_3 - 0.023X_1X_2X_3 + 0.005X_1^2X_2 + 0.002X_1^2X_3 + 0.012X_1X_2^2 \quad \text{(Eq. 3)}$$

where X_1, X_2, and X_3 were coded levels of T, Q and MD/FJ respectively. From table 2, results of ANOVA showed that experimental data were well represented by the obtained Cubic Model (R^2= 0.9992, $Adj.R^2$= 0.9958). According to the model, linear term of T (X_1) and Q (X_2) reached an extremely significant level (P <0.01), on the bulk density of barberry juice powder.

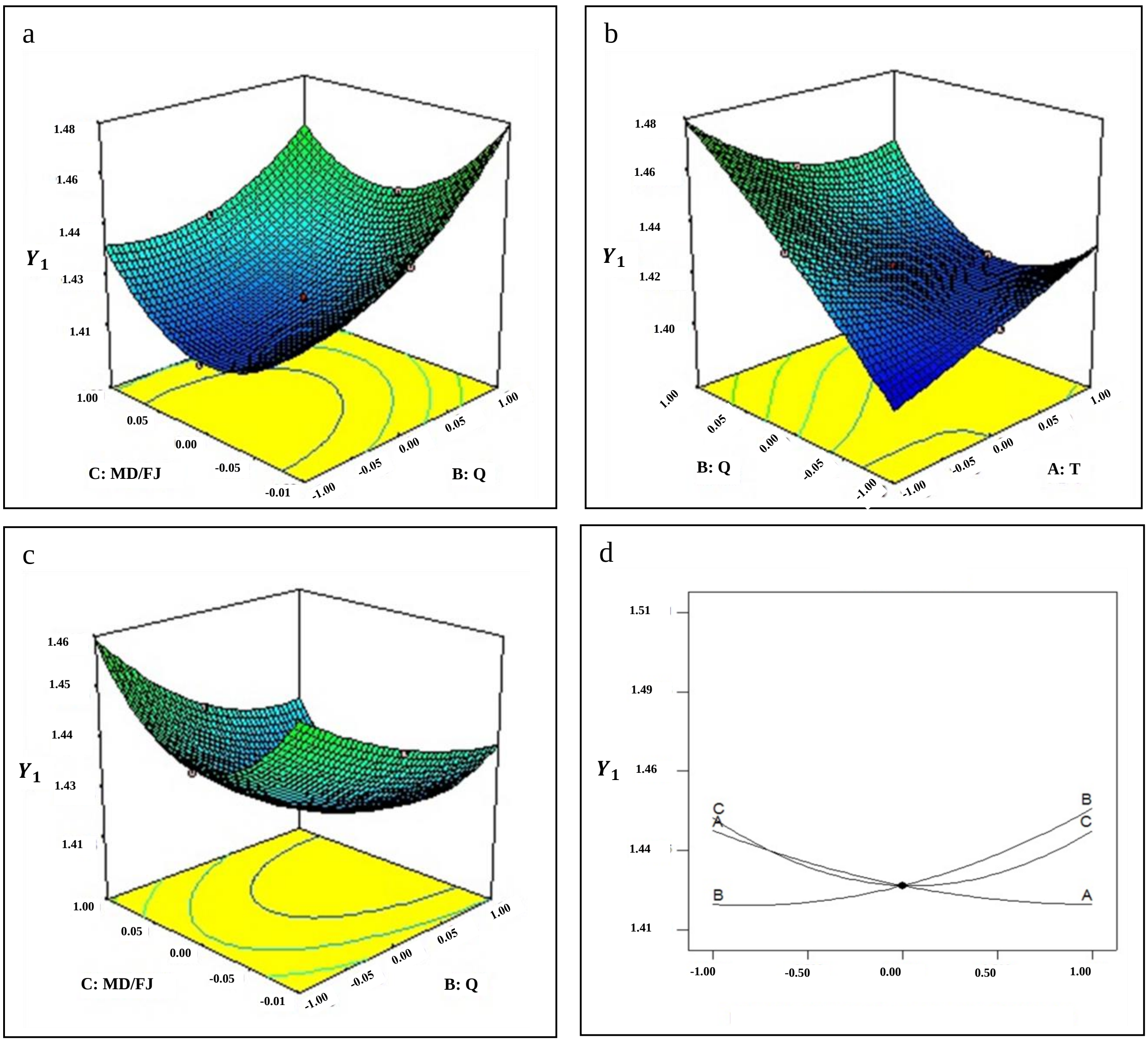

Fig. 1. Response surface (a–c) and perturbation plot (d) for the effects of variables on the bulk density of barberry juice powder

Table 2. ANOVA for respective regression models and model terms

Model Terms	Y_1		Y_2		Y_3		Y_4		Y_5		Y_6	
	F	P	F	P	F	P	F	P	F	P	F	P
Model	290.65	**	67.43	**	4.27	*	430.00	**	14.82	**	40.02	**
A_1	77.60	**	0.39	--	9.38	*	200.39	**	82.35	**	9.03	--
A_2	132.02	**	178.66	**	0.084	--	840.19	**	4.93	--	127.05	**
A_3	2.35	--	406.59	**	20.58	**	219.93	**	11.28	*	95.43	**
A_1A_2	337.98	**	5.75	*	0.13	--	71.00	**	6.37	*	0.12	--
A_1A_3	7.19	--	0.74	--	3.83	--	34.79	**	18.86	**	0.01	--
A_2A_3	64.69	*	2.01	--	0.067	--	34.79	**	0.98	--	0.44	--
A_{11}	25.26	*	0.11	--	0.54	--	3.70	--	2.39	--	3.70	--
A_{22}	66.08	*	10.67	*	4.34	--	5.35	--	6.48	*	17.35	*
A_{33}	288.84	**	0.31	--			3.70	--	2.39	--	5.88	--
$A_1A_2A_3$	1214.77	**					34.79	**			8.50	--
$A_{12}A_2$	11.74	*					14.20	*			41.69	**
$A_{12}A_3$	2.38	--					6.96	--			8.91	--
A_1A_{22}	67.60	**					14.20	*			1.42	--
R^2	0.999		0.989		0.846		0.999		0.950		0.994	
Adjusted R^2	0.996		0.974		0.648		0.997		0.886		0.969	

*Y_1: Bulk density, Y_2: Particle density, Y_3: Particle size, Y_4: Water solubility index, Y_5: Dispersability, and Y_6: Wettability, P: Notability

3.2. *Influence of Variables on the particle density of barberry juice Powder*

The regression models obtained for particle density given by Eq. (4) as follows:

$$Y_3 = 1.03 + 0.002X_1 + 0.052X_2 + 0.078X_3 + 0.010X_1X_2 + 0.004X_1X_3 - 0.006X_2X_3 - 0.003X_1^2 + 0.025X_2^2 - 4.19X_3^2 \quad \text{(Eq. 4)}$$

From table 2, results of ANOVA showed that experimental data were well represented by the obtained Quadratic Model (R^2= 0.9886, $Adj.R^2$= 0.9739). According to the model, linear term of Qf (X_2) and MD/FJ(X_3) reached an extremely significant level (P <0.01), on the bulk density of barberry juice powder.

Response surfaces for effects of variables on the particle density value are shown in Fig. 2a–c. As shown in Fig. 2 , the optimum conditions for the maximum value of particle density were around T=160℃, of= 38 and (MD/FJ) = 1.3. Particle density was lowest at a highest inlet air temperature (Fig. 2b, c, and d); Walton (2000) reported, the increase of drying air temperature generally causes the decrease in bulk, particle density and provides the greater tendency to the particles to hollow. The feed flow rate (Q) had positive effect on particle density value (Fig. 2a, b, and d). The feed flow rate was negatively affected the moisture content in the acai juice powder (Tonon et al., 2008). The highest particle density value of barberry juice powder was obtained at most of (MD/FJ) at 1.3 (Fig. 2a, c, and d).

3.3. *Influence of Variables on the particle size of barberry juice Powder*

The mean particle size for barberry juice powder samples produced at different inlet temperatures ranged from 500 to 27170 μm. From table 2, results of ANOVA showed that experimental data were represented by the obtained Quadratic Model (R^2= 0.8459, $Adj.R^2$= 0.6477). According to the model, linear term of T(X1) and MD/FJ(X3) reached an extremely significant level (P <0.05), (P <0.01) respectively, on the bulk density of barberry juice powder. The regression models obtained for particle size given by Eq. (5) as follows:

$$Y_3 = 11195.30 + 5424.60X_1 - 513X_2 - 8034.80X_3 + 727.25X_1X_2 + 3873.50X_1X_3 + 512X_2X_3 + 2515.73X_1^2 - 7123.77X_2^2 + 2515.73X_3^2 \quad \text{(Eq. 5)}$$

The inlet temperature was positively affected the particle size in the barberry juice powder. Higher inlet temperatures resulted in larger particles, which can be related to increased swelling as the drying temperature increased. When a particle is subjected to higher drying rates, the evaporation of moisture is rapid and promotes the formation of a hard crust that does not allow particle shrinkage during spray drying. However, if the inlet temperature is lower, the particle remains moist for a longer period of time and shrinks, thus decreasing its size (Nijdam & Langrish, 2006), Tonon et al. (2008), reported similar behaviors in spray-dried acai powders. Obon et al. (2009). The highest particle size value of barberry juice powder was obtained at most of inlet temperature (T=190℃) (Fig. 3b, c, and d). The effect of Q was no significant on particle size of barberry juice powder. (Fig. 3a, b and d). The ratio of MD/FJ was positively affected the particle size in the barberry juice powder. The higher maltodextrin concentrations were also led to produce the larger particles, which may be related to the feed viscosity, which exponentially increased with maltodextrin concentration. According to Masters (1979), the mean liquid droplet size varies directly with the liquid viscosity at constant atomizer speed.

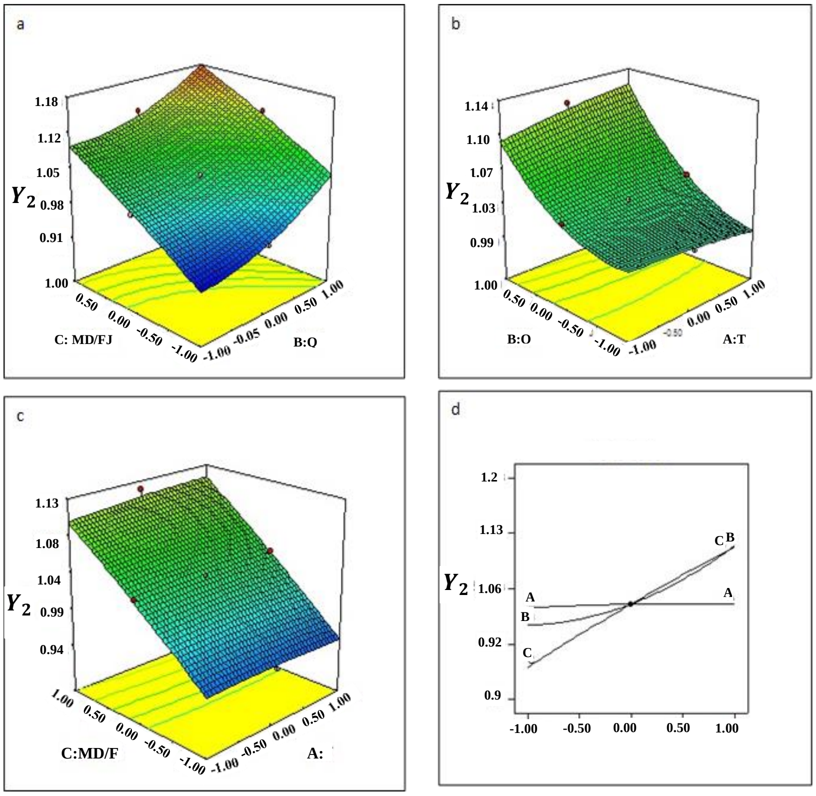

Fig. 2. Response surface (a–c) and perturbation plot (d) for the effects of variables on the “particle density” of barberry juice powder

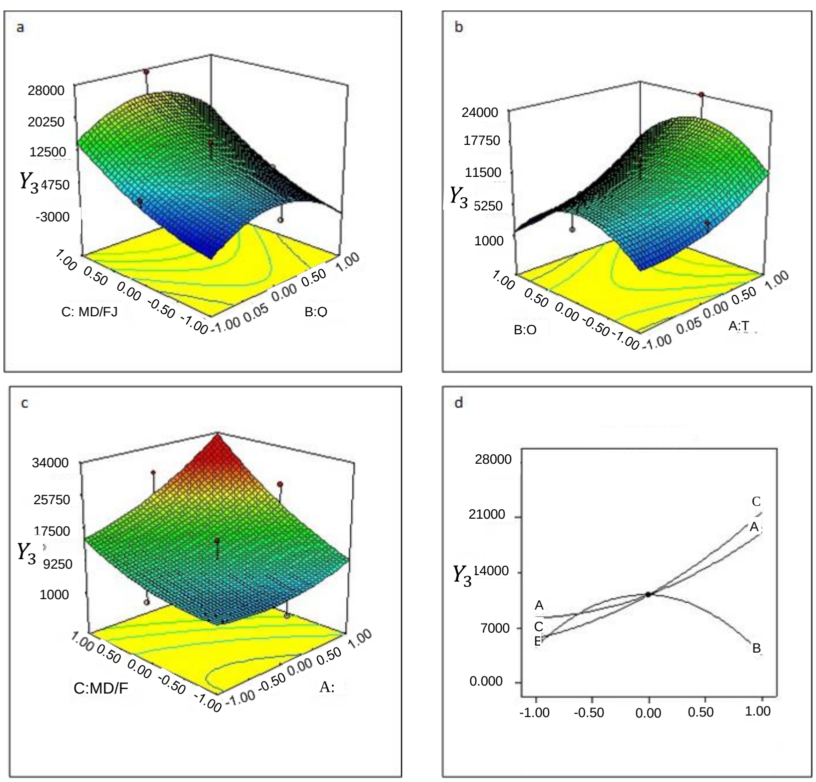

Fig. 3. Response surface (a–c) and perturbation plot (d) for the effects of variables on the particle size of barberry powder

The higher the liquid viscosity, the larger the droplets formed during atomization and thus, the larger particles obtained by spray drying. This is in an agreement with the results published by Jinapong et al. (2008), on instant soymilk powders produced by ultra filtration and spray-dried in a rotary atomizer. Keogh et al. (2003) observed a linear increase of the particles size with feed viscosity on spray drying of ultra-filtered whole milk concentrated, in a two-fluided nozzle atomizer. In both works, the authors attributed the increase in particle size to the increase on feed viscosity. In theexperimental region the highest particle size was observed in (T= 175℃, Qf=36 ml/ min and MD/FJ= 1.3).

3.4. *Influence of Variables on the Water solubility index of barberry juice Powder*

Water solubility index (WSI) is the reconstitution property used to study the effect of process parameters. From table 2, results of ANOVA showed that experimental data were well represented by the obtained Cubic Model (R^2= 0.9995, $Adj.\ R^2$= 0.9971). According to the model, linear term of T(X_1), Q(X_2) and MD/FJ(X_3) reached an extremely significant level (P <0.01), on the (WSI) of barberry juice powder. The regression models obtained for (WSI) given by Eq. (6) as follows:

$$Y_4 = 51.41 + 7.30X_1 + 95X_2 + 6X_3 - 2.34X_1X_2 - 4.02X_1X_3 + 0.92X_2X_3 - 2.48X_1^2 + 4.07X_2^2 - 2.48X_3^2 + 0.92X_1X_2X_3 + 1.11X_1^2X_2 + 4.02X_1^2X_3 + 0.27X_1X_2^2 \quad \text{(Eq. 6)}$$

The inlet temperature was positively affected the (WSI) in the barberry juice powder. The highest water solubility index was shown at an inlet temperature of 190℃, whereas the lowest water solubility index was shown at an inlet temperature of 160℃. (Table 1) and (Fig.4. b,c and d) (Santhalakshy, et al, 2015). Our results clearly show that water solubility index increased with an increase in the inlet temperature whereas the water absorption index decreased with increased inlet temperatures. A similar trend was reported by Phoungchandang and Sertwasana (2010), for spray drying of ginger juice. The instant property of a powder is defined as the ability of a powder to dissolve in water. Hence, the ideal powder would wet quickly and thoroughly, sink rather than float and disperse/dissolve without lumps (Hogekamp & Schubert, 2003). The feed flow rate was negatively affected the (WSI) in the barberry juice powder. The highest water solubility index was shown at lowest feed flow rate (Q=34 ml/min). (Table 1) and (Fig.4. a,b and d).(Phisut et al, 2012) Higher flow rates imply in a shorter contact time between the feed and drying air and making the heat transfer less efficient and thus caused the lower water evaporation. In fast feed flow rate was more powder moisture, resulting in water concentration gradient was lower becomes and less mass transport, consequently reduced water solubility index.The (WSI) increased when MD/FJ increased.(Fig. 3. a, c and d). The highest (WSI) was observed ratio MD/FJ= 1.3, Tin= 190℃. The interactions between variables (X_2X_3) had significant effect on (WSI) barberry juice powder. (Phisut, 2012) Additionally, an increased maltodextrin concentration did not cause a reduction in powder solubility. This variation may be attributed to the fact that maltodextrin has a superior water solubility. According to Cano-Chauca et al. (2005), maltodextrin was mainly used in the process of spray drying due to its physical properties, such as high solubility in water. Grabowski et al. (2006) also reported that the water solubility index of sweet potato powder increased as the amount of maltodextrin increased. The region of high (WSI) which could be easily identified from the three-dimensional plot was around MD/FJ= 1.3, Tin = 190℃, and Qf= 34 ml/min.

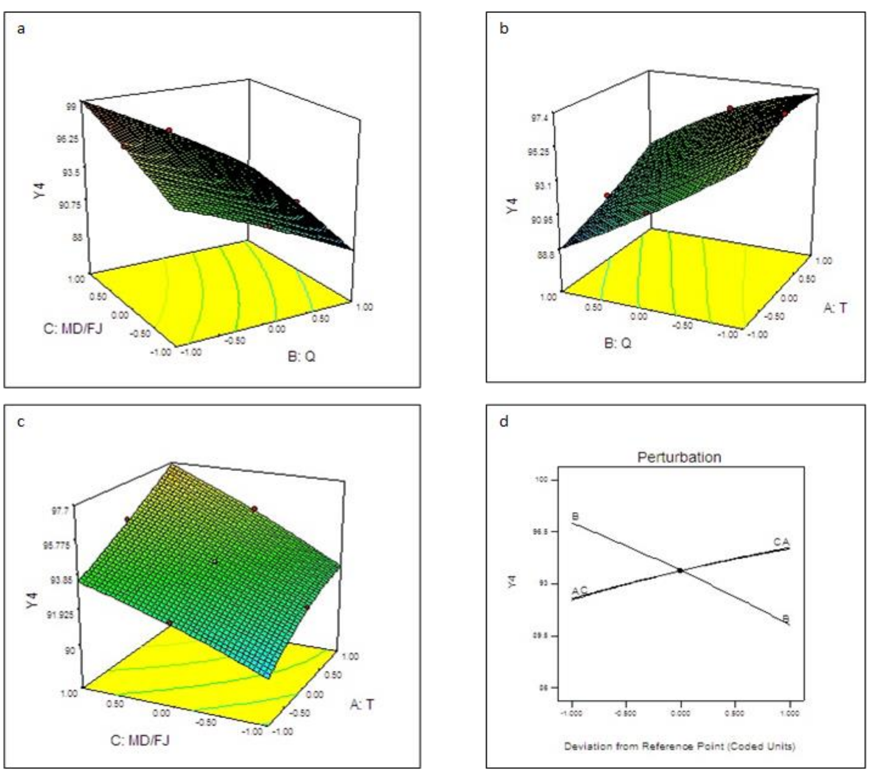

Fig. 4. Response surface (a–c) and perturbation plot (d) for the effects of variables on water solubility index (WSI) of barberry powde

3.5. *Influence of Variables on the dispersibility of barberry Powder*

Dispersibility is the reconstitution property used. From table 2, results of ANOVA showed that experimental data were represented by the obtained Quadratic Model (R^2= 0.9501, $Adj.R^2$= 0.8861). According to the model, linear term of T(X_1) reached an extremely significant level (P <0.01), on the dispersibility of barberry juice powder. The regression models obtained for dispersibility given by Eq. (7) as follows:

$$Y_5 = 51.41 + 7.52X_1 + 1.84X_2 + 2.78X_3 - 2.34X_1X_2 - 4.02X_1X_3 + 0.92X_2X_3 - 2.48X_1^2 + 4.07X_2^2 - 2.48X_3^2 \quad \text{(Eq. 7)}$$

The dispersibility of barberry juice powder showed significant difference (p< 0.01) between samples.

The inlet temperature was positively affected the dispersibility in the barberry juice powder.Fig.5.b,c and d. powders produced at an inlet temperature of 190℃ showed the highest dispersibility values (57.78),whereas sample produced at (160℃) showed the lowest value (32.3). (Santhalakshmy et al., 2015) From our results, it is clear that with an increase in the inlet temperature, dispersibility increased. A similar trend that was reported by Reddy et al. (2014), for spray-dried goat milk powder. The feed flow rate had a positive effect on dispersibility until reference point and then increase in the feed flow rate reduced dispersibility of barberry juice powder. As can be seen in Fig.3.a, b and d. The feed flow rate had a positive effect on dispersibility. Fig.5. a, c and d.

3.6. *Influence of Variables on the Wettability of barberry Powder*

Wettability can be defined as the ability of a powder bulk to be penetrated by a liquid because of capillary forces (Hogekamp & Schubert, 2003). From table 2, results of ANOVA showed that experimental data were well represented by the obtained Cubic Model (R^2= 0.0.9943, $Adj.\ R^2$= 0.9694). According to the model, linear term of Q (X_2) and MD/FJ (X_3) reached an extremely significant level (P <0.01), on the wettability of barberry juice powder. The regression models obtained for wettability given by Eq. (8) as follows:

$$Y_6 = 86.10 + 6X_1 - 22.50X_2 - 19.50X_3 + 0.34X_1X_2 + 0.09X_1X_3 + 0.66X_2X_3 3.32X_1^2 - 7.18X_2^2 - 4.18X_3^2 - 2.91X_1X_2X_3 + 14.41X_1^2X_2 + 6.66X_1^2X_3 - 2.66X_1X_2^2 \quad \text{(Eq. 8)}$$

The inlet temperature was no significantly affected the wettability in the barberry juice powder (Table 2). Wettability is inversely related to the particle size because larger particles show more spaces between them, being more easily penetrated by water. On the other hand, smaller particles are less porous, making it more difficult for the liquid to penetrate into the food matrix, which results in poor reconstitution properties (Cynthia & Bosco, 2014).

The feed flow rate and the ratio MD/FJ were negatively affected the wettaibility in the barberry juice powder (Fig. 6).

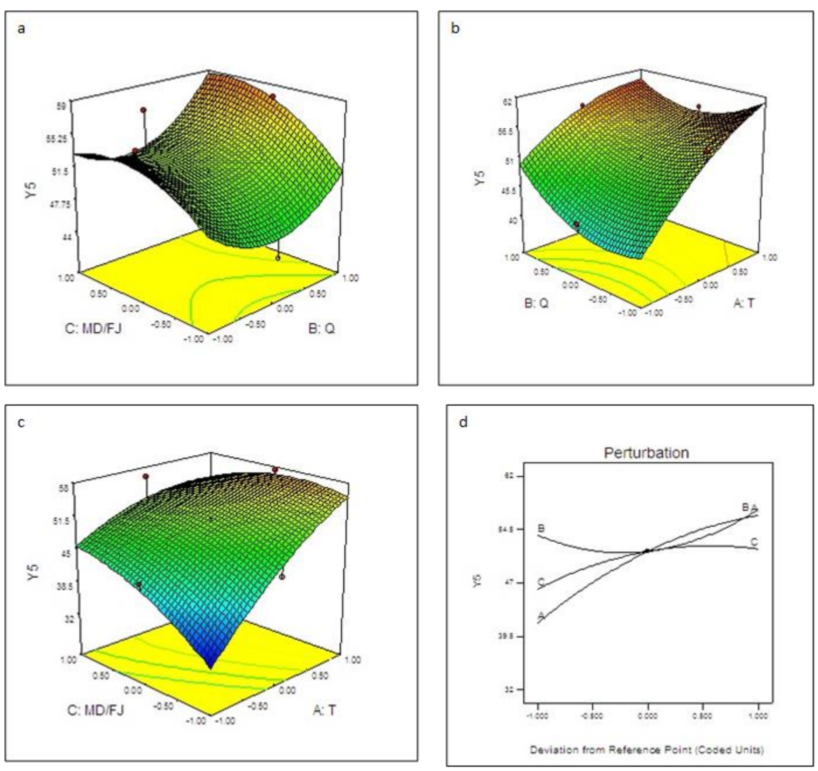

Fig. 5. Response surface (a–c) and perturbation plot (d) for the effects of variables on the dispersibility of barberry juice

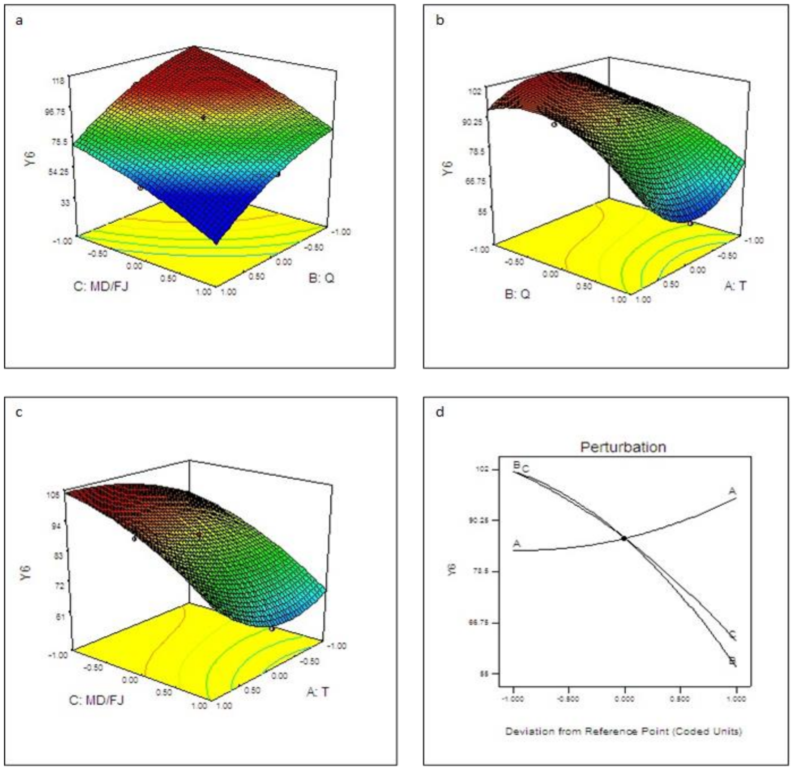

Fig. 6. Response surface (a–c) and perturbation plot (d) for the effects of variables on the wettability of barberry juice powder

Table 3. Numerical optimization for the optimum condition

Name	Goal	Low limit	Upper limit	Low weight	Upper weight	Importance
MD/FJ	Minimize	-1	1	1	1	3
T (℃)	Minimize	-1	1	1	1	3
Q ($\frac{ml}{\min}$)	Maximize	-1	1	1	1	3
Y_1 ($\frac{gr}{cm^3}$)	In range	1.411	1.51	1	1	3
Y_2($\frac{gr}{cm^3}$)	In range	0.917	1.146	1	1	3
Y_3 (μm)	In range	500	27170	1	1	3
Y_4 (%)	Maximize	86.84	100	1	1	3
Y_5 (%)	Maximize	41.1	62	1	1	3
Y_6 (%)	Maximize	55	100	1	1	3

*Y_1: Bulk density, Y_2: Particle density, Y_3: Particle size, Y_4: Water solubility index, Y_5: Dispersability, and Y_6: Wettability, P: Notability

Table 4. Solutions for optimum condition and the verification experimental results

Number	MD/FJ	T (℃)	Q ($\frac{ml}{\min}$)	Y_1 ($\frac{gr}{cm^3}$)	Y_2($\frac{gr}{cm^3}$)	Y_3 (μm)	Y_4 (%)	Y_5 (%)	Y_6 (%)
Predicted values	1.13 (-0.69)	181 (0.38)	38 (1)	1.466	1.06	500.04	89.76	56.22	71.47

*Y_1: Bulk density, Y_2: Particle density, Y_3: Particle size, Y_4: Water solubility index, Y_5: Dispersability, and Y_6: Wettability, P: Notability

3.7. Optimization and Verification

T, Q and MD/FJ were optimized simultaneously through a desirability function which would satisfy all the responses with requirements to obtain optimum spray drying conditions. The ultimate aim was to obtain the highest water solubility index, dispersibility and Wettability of barberry juice powder. So, the optimization processes for the variables were investigated in the present study. The numerical optimization for the optimum conditions during spray drying is shown in table 3. Through comprehensive optimization, the predicted optimum conditions were obtained at MD/FJ=1.131, T=181℃, and Q=38 ml/min. (Table 4).

Hence, the optimum conditions for preparation of barberry powder by spray drying were as follows: dry matter weight ratio of maltodextrin and the dry matter weight of barberry juice was 1.131

inlet air temperature was 181℃, and shift of feed flow rate was 38 ml/min. Under these conditions, the response values were bulk density= 1.466(g/cm3), particle density= 1.06(g/cm3), particle size= 500.04(μm), water solubility index=89.76% ,dispersibility=56.22% and Wettability=71.47%.

4. Conclusions

RSM and perturbation plot were successfully applied for estimating the effect of T, Q and MD/FJ on the quality attributes (bulk density, particle density, particle size, water solubility index, dispersibility and Wettability) of barberry juice powder. Results showed that MD/FJ had the most significant among the variables. The optimum conditions maximizing water solubility index, dispersibility and Wettability of barberry juice powder were found as inlet air temperature of 181°C, Qf of 38 (ml/min) and MD/FJ of 1.13,. Under these conditions, the response values were bulk density of 1.466(g/cm3) ,particle density of 1.06(g/cm3), particle size of 500.04 µm, water solubility index 89.76%, dispersibility of 56.22% and Wettability of 71.47%.

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