Process optimization of spray drying of beetroot Juice

Bhupinder Singh¹ · Bahadur Singh Hathan²

Revised: 17 April 2017 / Accepted: 26 April 2017 / Published online: 9 June 2017
© Association of Food Scientists & Technologists (India) 2017

Abstract The aim of this study was to optimize the spray drying process for beetroot juice. Influence of feed flow rate (8, 10 and 11 mL/min), processing temperature (140, 150 and 160 °C) and maltodextrin concentration (20, 25, and 30%) on packed bulk density, moisture content and betalain content of beetroot powder were assessed using response surface methodology. The following optimum process parameters were determined; feed flow rate feed flow rate of 10 mL/min, processing temperature of 149 °C and maltodextrin concentration of 20%. The predicted values for packed bulk density, moisture content and betalain content were 0.62 g/mL, 6.12 and 33.84 mg/100 g of dry matter, respectively. Within the optimum parameters, the experimental values for packed bulk density, moisture content and betalain content were 0.62 ± 0.1 g/mL, 6.10 ± 0.1 and 33.14 ± 0.1 mg/100 gm of dry matter. The similarity of the experimental results to the predicted values verified the models.

Keywords Beetroot · Response surface methodology · Spray-drying · Optimization

Introduction

Beta vulgaris L., commonly known as the beetroot, is a root vegetable grown all over the world. Beetroot are composed of 12–20% dry matter, 4–12% sugar, 1.5% protein, 0.1% fat, 0.8% fiber and many minerals such as sodium, potassium, phosphorus, calcium, and iron, along with small amounts of vitamins. It also contains phenolic acids including *p*-coumaric, protocatechuic, ferulic, vanillic, *p*-hydroxybenzoic and syringic acids (Kujala et al. 2000; Vulic et al. 2012).

Beetroot is excellent source of nitrogenous pigments such as betacyanins in which color varies from purple to violet and betaxanthins that includes color range from yellow to orange. In beetroot juice, red–violet colored betacyanins constitutes of 75–78% of betanin pigments were classified as antioxidants help to stop or delay in the oxidation processes, and exhibit anti-tumour and anti-atherosclerotic effects. It is proverbial that phenolic resin plants increased the antioxidant activity by scavenging of free radicals and consequently stop diseases such as cancer and vas diseases (Ravichandran et al. 2013). Singh et al. (2016) reported the higher values of total phenolic content and free radical inhibition in corn extrudates by incorporation of beetroot powder at different extrusion temperatures. Mridula et al. (2016) has reported use of beetroot juice as a parameter along with groundnut meal and refined wheat flour for development of nutritious pasta that shows high antioxidant activity. The interest in beetroot powder has increased because of the recognition of their potential health benefits.

Beetroot is a seasonal vegetable, so its availability as fresh vegetable is limited only for a specific time period. Hence spray drying of beetroot juice may be a good alternative to use its health loving components available

✉ Bhupinder Singh
bhupimander@rediffmail.com

Bahadur Singh Hathan
bshathan@yahoo.co.in

¹ Department of Food Technology, CDL State Institute of Engineering and Technology, Panniwala Mota, Sirsa, Haryana, India

² Department of Food Engineering and Technology, Sant Longowal Institute of Engineering and Technology, Longowal, Punjab 148106, India

through out the season. Spray-drying has been generally utilized for commercial production of fruit powder and also in the production of milk powders (Kim et al. 2009). Spray-dried powders have good reconstititional characteristics, low water activity and are suitable for transport and storage (Kha et al. 2010). The advantages of spray drying include hygienic conditions during processing, low operational costs, and short contact time (Sagar and Suresh Kumar 2010). During spray drying, sticky products can be generated, thereby adhering to the internal wall of drying chamber leads to the lower yield (Hennigs et al. 2001). The use of high molecular maltodextrin as an encapsulation or carrier agent in spray drying has been introduced to tackle the problem (Ratanasiriwat et al. 2013; Mishra et al. 2017). It can also increase the glass transition temperature and stability during storage (Fazaeli et al. 2012).

Food powder properties, for example, moisture content, bulk density and morphology were influenced by gulf temperature. Regularly, the bay temperature utilizes for spray dry system for sustenance powder is 140–220 °C. However according to scientific literature suitable temperature for spray drying of fruit or vegetable juices is found in the range 140–180 °C (Tonon et al. 2009; Fang and Bhandari 2011).

As per the best of our knowledge the information on the prediction of packaged bulk density, moisture content and betalain content of beetroot powder based on processing variables, such as feed flow rate, processing temperature and maltodextrin for the production of beetroot powder is scarce. The aim of this work was to study the combined effects of the spray-drying parameters including feed flow rate, processing temperature and maltodextrin to maximise the betalain content as well as to minimize the moisture content of the beetroot powder.

Materials and methods

Materials

Raw material for the study was 100% fresh beetroot juice. Fresh and uniform sizes of round shaped beetroot were procured from the local market, Sangrur (Punjab). Around 20 kg of beetroot was procured from market. Care was taken to ensure that there was no bruising, cutting or any sign of physical injury. Beetroot were washed in running water and cleaned properly and then juice was extracted by juicer. Extracted beetroot juice was filtered with the help of muslin cloth. Maltodextrin used as a drying agent was procured from a local supplier.

Methods

Preparation of beetroot powder

The drying of prepared juice blended with drying agents was carried out in a tall type laboratory scale spray dryer (S.M. Scientech, Calcutta, India), based on the same principle as the co-current flow atomizer i.e. the product is sprayed in the same direction as the drying air. Atomizer was engaged for spray drying process is a two-fluid nozzle with inside diameter of 0.5 mm. Feed was metered into the dryer by means of a peristaltic pump. For spray drying process, a sample of 500 g was taken. Spray drying was carried out with feed flow rate (8, 10 and 11 mL/min), processing temperature (140, 150 and 160 °C) and maltodextrin concentration (20, 25, and 30%) shown in Table 1. Powder obtained from spray drying was collected in the cyclone, then transferred to glass twist-off jars. Dried powder was stored for 6 months in jars in a dark place. All experiments were done in triplicate.

Powder tests

Bulk density

The packed bulk density was determined by measuring tare weight of 100-mL cylinder. The powders were consolidated by tapping on a rubber mat until the volume was reduced and reasonably constant. The volume of the powder was read in mL and bulk density recorded as g/mL.

Estimation of moisture content

Five grams of powder was accurately weighed into a petri-dish previously dried and weighed. The dish containing the powder was heated in an oven at 105 °C for 4 h. The % moisture was calculated from the loss of mass after 4 h drying on wet basis (Ranganna 1986).

Betalain content

Quantification of betalain (BT) was performed by the spectrophotometric method as described by Cai and Corke (1999) and Cassano et al. (2007) using UV–Vis spectrophotometer (Hach DR 6000, Germany). Pigments were extracted from the sample with methanol at pH 6.5. The determination of betalain concentration, i.e. violet and yellow pigments, was calculated in terms of betacyanin (BC) and indicaxanthin-I (IX) respectively. Pigment content calculations were based on the absorptivity values A , which were 1120 for betacyanin (at 538 nm) and 750 for indicaxanthin-I (at 480 nm). The absorbance readings were made against methanol as blank. All analyses were done in

Table 1 Central composite design with experimental values of response variables for beetroot powder

Run no.	Process variables			Responses		
	Feed flow rate (mL/min), (X ₁)	Processing temperature (°C), (X ₂)	Maltodextrin (%), (X ₃)	Packed bulk density (g/mL)	Moisture content, (%)	Betalain content (mg/100 gm of dry matter)
1	9	150	25	0.687	4.72	30.10
2	8	160	30	0.618	4.36	12.03
3	9	150	25	0.681	4.72	30.10
4	8	140	30	0.702	4.68	17.34
5	10	140	30	0.719	4.31	12.25
6	11	150	25	0.631	5.04	12.87
7	8	150	25	0.697	4.79	21.54
8	9	150	25	0.681	4.76	30.10
9	8	140	20	0.721	5.48	24.23
10	10	160	20	0.638	5.97	30.10
11	8	160	20	0.747	5.25	15.76
12	9	150	25	0.680	4.70	30.10
13	10	140	20	0.618	6.21	27.94
14	9	150	17	0.674	6.5	38.52
15	9	150	25	0.681	4.72	30.10
16	9	150	33	0.664	4.26	22.98
17	9	134	25	0.705	4.89	16.42
18	9	167	25	0.654	4.40	13.10
19	9	150	25	0.687	4.89	28.74
20	10	160	30	0.639	3.95	15.74

triplicate at room temperature (28 °C). The betalain content collectively along with betacyanin and indicaxanthin, expressed as mg/L, and was calculated individually by using the following equation proposed by Cai and Corke (1999).

$$B = \frac{A \times DF \times MW \times 1000}{\varepsilon \times L}$$

where A is the absorption at 538 and 480 nm for betacyanins and indicaxanthins, respectively; DF is the dilution factor and L the path length of the cuvette (1 cm). For MW and ε , the molecular weights (550 and 308) and extinction coefficients (60,000 and 48,000 L mol⁻¹ cm⁻¹) of the representative compounds betacyanin and indicaxanthin have been considered (Cai and Corke 1999; Cassano et al. 2007).

Scanning electron microscopy

Scanning electron microscopy was employed to examine the micro-structure of spray dried beetroot powder. The cells of maltodextrin and spray dried beetroot powder were fixed with glutaraldehyde and subjected to critical drying with increasing concentration of aqueous ethanol (20–100 mL/100 mL). The fixing was done to accomplish

a fixed and stabilized structure of biological systems. Prior to viewing, the dried samples were fractured and mounted on aluminum stub using a double backed cellophane tape, coated in auto fine coater, JEOL-JFC-1600, with gold palladium (60:40, g:g). The fractured surfaces of samples were examined with a scanning electron microscope (SEM), JEOL, Tokyo, Japan, Model No., JSM-6610-LV, operating at 10 and 20 kV.

Experiment design, statistical analysis and optimization

Response surface methodology was used to investigate the optimum combination of spray drying conditions on the physicochemical properties of the spray-dried powders. A central composite design with three variables, feed flow rate (8, 10 and 11 mL/min), processing temperature (140, 150 and 160 °C), and maltodextrin concentration (20, 25, and 30%) shown in Table 1 was consisted of 20 runs. The response variables included packed bulk density, moisture content and betalain content. The second-order polynomial equation was fitted to the experimental data of each dependent variable.

$$Y_{ku} = \beta_{k0} + \sum_{i=1}^n \beta_{ki}x_{iu} + \sum_{i=1}^n \beta_{kii}x_{iu}^2 + \sum_{i=1}^{n-1} \sum_{j=i+1}^n \beta_{kij}x_{iu}x_{ju} + e_{ku}$$

where term Y_{ku} is response variable, Y_{1u} is packed bulk density (g/mL of beetroot powder). Y_{2u} is moisture content (wb%), Y_{3u} is betalain content of the beetroot powder. Where, β_{k0} is the value of the fitted response at the centre point of the design, i.e. point (0,0) and β_{ki} , β_{kii} and β_{kij} are the linear, quadratic and interactive regression terms, respectively.

The main aim of the optimization of the spray drying process for beetroot juice was focused to discover the levels of independent variables such as feed flow rate, processing temperature and maltodextrin %, which would result in minimum packed bulk density, minimum moisture content and maximum betalain content of beetroot powder. To achieve this goal, a criterion was adopted by selecting lower and upper limit for individual parameter to achieve the maximum desirability. By using this approach, observed values were compared with predicted values for each parameter. According to these parameters desirability of model was found and corresponding to the maximum desirability of the values of different parameters such as feed flow rate, processing temperature and maltodextrin % were noted. Statistical analysis was done with the help of Design Expert statistical software (version 7.0.1, Stat-Ease Inc., Minneapolis, MN) to evaluate the effect of various process parameters on measured responses at 5% level of significance. The statistical significance of fitted model was done using Analysis of variance (ANOVA). The competency of the models was determined using model analysis, lack-of-fit tests, and R^2 (coefficient of determination). Contribution of independent variables in the prediction of dependent variable was judged according to the value of β coefficient. The higher positive value of β of a parameter denotes the greater effect of that parameter and vice versa. Interaction of any two independent variables was shown by generating response surface plots by holding the value of third-and fourth-variable as constant.

Results and discussion

Influence of feed flow rate (8, 10 and 11 mL/min), processing temperature (140, 150 and 160 °C) and maltodextrin concentration (20, 25, and 30%) on packed bulk density, moisture content and betalain content of beetroot powder were assessed using response surface methodology as shown in Table 1.

Diagnostic checking of fitted models and response surfaces

The results of second-order response surface model within the kind of analysis of variance (anova) are given in Table 2. The results indicated that the fitted quadratic models accounted for quite 90% of the variation within the experimental information that were extremely significant ($R^2 > 0.90$).

Packed bulk density

The magnitude of P values from Table 2 revealed that all linear and interaction terms except feed flow rate and processing temperature have significant effect on packed bulk density during spray drying. Further, Quadratic terms feed flow rate and maltodextrin has significant effect on packed bulk density. The model F-value was 224.35, which indicated that the model was significant. The relative magnitude of β values (Table 2) indicates the maximum positive effect of maltodextrin ($\beta = 0.011$) followed by negative effect of processing temperature ($\beta = -0.015$) and feed flow rate ($\beta = -0.035$) on packed bulk density. The quadratic and interaction terms of all the process parameters have least effect on packed bulk density as compared to the linear terms of process variables.

Packed bulk density of beetroot powder varied from 0.53 to 0.74 g/mL. According to Fig. 1 temperature and maltodextrin concentration significantly affected the packed bulk density of beetroot powder, however feed flow rate did not show any significant effect on packed bulk density of powder. Fig. 1a shows that packed bulk density of beetroot powder decreased with the increase in temperature. Packed bulk density however was not affected much by feed flow rate. Tonon et al. (2008) observed similar findings while spray drying of acai juice powder. The decrease in bulk density with increase in drying air temperature might be due to particle inflation-ballooning or puffing (Walton and Mumford 2000). As shown in Fig. 1b an increase in concentration of carrier agent i.e. maltodextrin caused a decreasing trend in packed bulk density. This effect may be attributed to the fact that maltodextrin addition minimizes thermoplastic particles from sticking (Goula and Adamopoulos 2010). The volume of air trapped in the particle increases with increase in the concentration of malt dextrin due to its skin forming nature (Kwapinska and Zbicinski 2005). Figure 1c depicts that both the processing temperature and maltodextrin collectively had significant effect on the packed bulk density of beetroot powder.

Table 2 ANOVA table showing the variable as linear, quadratic, and interaction terms on each response variable and coefficients for the prediction models

Source	df	Bulk density (g/mL)			Moisture content (%)			Betain content (mg/100 gm of dry matter)		
		β	F Value	P value	β	F Value	P value	β	F Value	P value
Model	9	0.67	224.35	<0.0001	4.80	280.42	<0.0001	29.77	354.80	<0.0001
A-feed flow rate	1	−0.035	489.91	<0.0001	0.17	39.95	<0.0001	2.19	132.08	<0.0001
B-processing temperature	1	−0.015	187.95	<0.0001	−0.15	62.76	<0.0001	−0.79	22.06	0.0008
C-malto dextrin %	1	0.011	95.84	<0.0001	−0.84	2004.79	<0.0001	−5.00	858.79	<0.0001
A ²	1	−5.007E−003	5.76	0.0373	0.099	7.98	0.0180	−5.34	1004.77	<0.0001
B ²	1	−4.831E−004	0.28	0.6098*	−0.034	4.86	0.0520*	−5.46	1072.03	<0.0001
C ²	1	−4.875E−003	25.57	0.0005	0.25	233.69	<0.0001	0.41	5.41	0.0424
AB	1	−3.750E−004	0.043	0.8392*	−9.375E−003	0.095	0.7638*	2.43	123.73	<0.0001
AC	1	0.047	677.38	<0.0001	−0.42	189.75	<0.0001	−2.43	123.76	<0.0001
BC	1	−0.026	477.96	<0.0001	−0.026	1.68	0.2237*	0.56	6.60	0.0280
Residual	10									
Lack of fit	5		1.18	0.4291*		0.32	0.8838*	2.19	1.50	0.3341*
Pure error	5									
Cor total	19									
R ²		0.995			0.996			0.993		
Adj R ²		0.990			0.992			0.986		

* Non significance at 5% level

Moisture content

Table 2 indicates that all linear terms of process variables have significant effect ($P < 0.05$) on moisture content. Further, quadratic effect of feed flow rate and maltodextrin % and interaction of 'Feed flow rate and maltodextrin %' have significant effect on moisture content during spray drying ($P < 0.05$). The magnitude β values indicates the maximum positive effect of feed flow rate ($\beta = 0.17$) followed by negative effect of processing temperature ($\beta = -0.15$) and maltodextrin % ($\beta = -0.84$).

The interactive effect of feed flow rate and processing temperature on the moisture content showed significant effect on the moisture content of beetroot powder Fig. 2a. As feed flow rate was increased the moisture content was increased. This may be attributed shorter time contact time at higher feed rate that made the heat transfer less efficient, thus, reducing the rate of water evaporation. A decrease in moisture content from 6.21 to 3.95% (Table 1) was observed with increase in the temperature from 140 to 160 °C. Solval et al. (2012) and Tonon et al. (2008) also explained that higher inlet temperature, higher rate of heat transfer because due to greater driving force for moisture evaporation and so a significant reduction in moisture content in the spray dried powder was observed. Figure 2b presents the interactive effect of maltodextrin and feed flow rate on moisture content of the finished spray dried powder.

Both maltodextrin and feed flow rate collectively had no significant effect on the moisture content of powder but feed flow rate showed an obvious effect on moisture content of beetroot powder. As the feed flow rate increased moisture content was also increased in powder (Fig. 2b; Table 1). According to the Fig. 2c maltodextrin and processing temperature showed statistically significant effect on moisture content of beetroot powder. Increase in the maltodextrin level resulted in the decreased moisture content of beetroot powder. Kha et al. (2010) reported that by increasing the maltodextrin concentration the level of feed solid were increased and so reduced the total level of moisture for evaporation.

Betain content

The magnitude of P value from Table 2 indicates significant effects of linear, quadratic and interactive terms on betain content of beetroot powder. The F-value clearly indicated that the model was significant. The sign of β coefficients revealed that the linear terms of all variables except feed flow rate had negative effect on total betain content. The feed flow rate have the positive effect ($\beta = 2.191$) followed by negative effect by processing temperature ($\beta = -0.7919$) and maltodextrin % ($\beta = -5.0$) on total betain content.

Fig. 1 Response surface plot showing the effect of **a** feed flow rate and processing temperature **b** feed flow rate and maltodextrin % and **c** processing temperature and maltodextrin on packed bulk density of

beetroot powder. A constant value was imposed to the third independent variable: **a** feed flow rate = 9 mL/min; **b** processing temperature = 150°; **c** maltodextrin % = 25

Betalain content of the beetroot powder varied from 12.02 to 38.51 mg/100 g. According to Fig. 3 temperature, maltodextrin and feed flow rate significantly affected the betalain content of beetroot powder. The effects of feed

flow rate and processing temperature are shown in Fig. 3a, as temperature was increased from 140 to 160 °C the betalain content decreased. This may be attributed to concentration effect of maltodextrin (Mishra et al. 2014).

Fig. 2 Response surface plot showing the effect of **a** feed flow rate and processing temperature **b** feed flow rate and maltodextrin % and **c** processing temperature and maltodextrin % on moisture content of

beetroot powder. A constant value was imposed to the third independent variable: **a** feed flow rate = 9 mL/min; **b** processing temperature = 150°; **c** maltodextrin % = 25

Figure 3b showed the interactive effect of feed flow rate and maltodextrin on the betalain content of beetroot powder. As the feed flow rate was increased the betalain content was decreased. Increased level of maltodextrin effectively encapsulated the phytonutrients of juice and protected against thermal degradation (Mishra et al. 2015).

Figure 3c depicted that both the processing temperature and maltodextrin collectively had significant effect on the betalain content of beetroot powder. Some studies reported betalain degradation during thermal processing, including isomerization, decarboxylation, or cleavage by heats and acids (Herbach et al. 2004).

Fig. 3 Response surface plot showing the effect of **a** feed flow rate and processing temperature **b** feed flow rate and maltodextrin % and **c** processing temperature and maltodextrin on Betalain content of

beetroot powder. A constant value was imposed to the third independent variable: **a** feed flow rate = 9 mL/min; **b** Processing temperature = 150°; **c** maltodextrin % = 25

Selection of optimum conditions

Numerical optimization method was used to optimize the spray drying process of beetroot juice by assigning equal importance of “3” to all process parameters such as feed flow rate, processing temperature and maltodextrin concentration. The main criterion for constraints optimization was minimum packed density, moisture content and maximum betalain content. All the factors contributes major

factor in overall acceptability. Therefore, based on relative contribution to quality of final product, the importance given to different responses were 3, 4 and 4 for packed bulk density, moisture content and betalain content. The optimum parameters for preparation of beetroot powder were feed flow rate feed flow rate of 10 mL/min, processing temperature of 149 °C and maltodextrin concentration of 20%.

Fig. 4 Electron microscopy image of maltodextrin (a) and spray dried beetroot powder with maltodextrin as encapsulating agent (b)

Verification of optimized conditions

The fitness of the model equations for predicting optimum response values was investigated under the conditions: feed flow rate of 10 mL/min, processing temperature of 149 °C and maltodextrin concentration of 20%. These conditions were considered to be optimum by the RSM optimization approach. To verify the validity of the optimized conditions, experiments were performed to evaluate the experimental results versus predicted values of the output. The experiments were carried out thrice. The efficiency on the extraction of packed bulk density, moisture content and betalain content change under these optimum conditions was found to be 0.62 g/mL, 6.12 and 33.84 mg/100 g of dry matter, and the experimental value was 0.62 ± 0.1 g/mL, 6.10 ± 0.1 and 33.14 ± 0.1 mg/100 g. The mean values obtained through the experiments were compared with the predicted values. The values obtained through confirmation experiments are within 95% of predicted values. It shows that the optimal values are valid within the specified range of process variables.

Scanning electron microscopy of optimized sample

Figure 4a shows the maltodextrin was the encapsulating agent due to its ballooning and puffing property and used as a carrier in spray drying of beetroot juice. Figure 4b shows powder obtained at optimized spray drying conditions such as feed flow rate of 10 mL/min, processing temperature of 149 °C and maltodextrin concentration of 20% has spherical shape of large diameter with several dents on upper surface of the material. Larger beetroot particle diameter of microcapsules with MD could be caused by the “ballooning and puffing” tendency of maltodextrin. Microstructure study on the spray dried fruit and vegetable powder in which malt dextrin act as a carrier are spherical in shape with several dents on the surface (Fazaeli et al. 2012). The formation of the dents on the upper surface is usually attributed to shrinkage of particle due to heavy moisture

loss followed by cooling. Scientific literature has stated that the morphology of particles could have an influence on the solubility of particles, which is an important factor in powder product design and its future application (Walton and Mumford 2000). In the presented research the size of the particle did not influence the solubility of powders.

Conclusion

The processing conditions for the spray drying of beetroot juice was optimized by response surface methodology with central composite design. Feed flow rate (8–11 mL/min), inlet temperature (140–160 °C) and maltodextrin concentration (20–30%) significantly affected packed bulk density, moisture content and betalain content. Bulk density was not significantly affected by feed flow rate however temperature and maltodextrin affected the bulk density significantly. Feed flow rate 10 mL/min, inlet temperature 149 °C and maltodextrin concentration 20% was found to be optimum and produced powder of low packed bulk density, moisture content and good amount of betalain. The corresponding values for packed bulk density, moisture content and betalain content of optimum powder 0.62 ± 0.1 g/mL, 6.10 ± 0.1 and 33.14 ± 0.1 mg/100 gm of dry matter.

References

- Cai Y, Corke H (1999) *Amaranthus* betacyanin pigments applied in model food system. *J Food Sci* 64(5):869–873
- Cassano A, Conidi C, Timpone R, Avella M, Drioli E (2007) A membrane-based process for the clarification and the concentration of the cactus pear juice. *J Food Eng* 80:914–921
- Fang Z, Bhandari B (2011) Effect of spray drying and storage on the stability of bayberry polyphenols. *Food Chem* 129:1139–1147
- Fazaeli M, Emam-Djomeh Z, Ashtari AK, Omid M (2012) Effect of process conditions and carrier concentration for improving drying yield and other quality attributes of spray dried black mulberry (*Morus nigra*) juice. *Int J Food Eng* 8:1–20

- Goula AM, Adamopoulos KG (2010) A new technique for spray drying orange juice concentrate. *Innov Food Sci Emerg Technol* 11:342–351
- Hennigs C, Kockel TK, Langrish TA (2001) New measurements of the sticky behavior of skim milk powder. *Dry Technol* 19:471–484
- Herbach KM, Stinzing FC, Carle R (2004) Impact of thermal treatment on color and pigment pattern of red beet (*Beta vulgaris* L.) preparations. *J Food Sci* 69:C491–C498
- Kha CT, Nguyen HM, Roach DP (2010) Effects of spray drying conditions on the physicochemical and antioxidant properties of the Gac (*Momordica cochinchinensis*) fruit aril powder. *J Food Eng* 98:385–392
- Kim EHJ, Chen D, Pearce D (2009) Surface composition of industrial spray-dried milk powders. 2. Effects of spray drying conditions on the surface composition. *J Food Eng* 94(2):169–181
- Kujala TS, Loponen JM, Klika KD, Pihlaja K (2000) Phenolics and betacyanins in red beetroot (*Beta vulgaris*) root: distribution and effect of cold storage on the content of total phenolics and three individual compounds. *J Agric Food Chem* 48:5338–5342
- Kwapinska M, Zbicinski I (2005) Prediction of final product properties after co-current spray drying. *Dry Technol* 23:1653–1665
- Mishra P, Mishra S, Mahanta CL (2014) Effect of maltodextrin concentration and inlet temperature during spray drying on physicochemical and antioxidant properties of amLa (*Emblica officinalis*) juice powder. *Food Bioprod Process* 92(3):252–258
- Mishra P, Rai GK, Mahanta CL (2015) Process standardization food development of spray dried lemon juice powder and optimization of amLa lemon based RTS (ready to serve) drink using response surface methodology. *J Food Process Preserv* 39:1216–1228
- Mishra P, Brahma A, Seth D (2017) Physicochemical, functionality and storage stability of hog plum (*Spondia pinnata*) juice powder produced by spray drying. *J Food Sci Technol*. doi:10.1007/s13197-017-2531-x
- Mridula D, Gupta RK, Bhadwal S, Khaira H, Tyagi SK (2016) Optimization of food materials for development of nutritious pasta utilizing groundnut meal and beetroot. *J Food Sci Technol* 53:1834
- Ranganna S (1986) Handbook of analysis and quality control for fruits and vegetable products, 2nd edn. Tata McGraw Hill Publ Co., New Delhi
- Ratanasiriwat P, Worawattanamatekul W, Klaypradit W (2013) Properties of encapsulated wasabi flavour and its application in canned food. *Int J Food Sci Technol* 48:749–757
- Ravichandran K, Thaw Saw NMM, Mohdaly AAA, Gabr AMM, Kastell A, Riedel H, Cai Z, Knorr D, Smetanska I (2013) Impact of processing of red beet on betalain content and antioxidant activity. *Food Res Int* 50(2):670–675
- Sagar VR, Suresh Kumar P (2010) Recent advances in drying and dehydration of fruits and vegetables: a review. *J Food Sci Technol* 47(1):15–26
- Singh JP, Kaur A, Shevkani K, Singh N, Singh B (2016) Physicochemical characterisation of corn extrudates prepared with varying levels of beetroot (*Beta vulgaris*) at different extrusion temperatures. *Int J Food Sci Technol* 51:911–919
- Solval KM, Sundarajan S, Alfaro L, Sathivel S (2012) Development of cantaloupe (*Cucumis melo*) juice powder using spray drying technology. *LWT-Food Sci Technol* 46:287–293
- Tonon VR, Brabet C, Hubinger M (2008) Influence of process conditions on the physicochemical properties of acai powder produced by spray drying. *J Food Eng* 88:411–418
- Tonon RV, Baroni AF, Brabet C, Gibert O, Pallet D, Hubinger MD (2009) Water sorption and glass transition temperature of spray dried acai (*Euterpe oleracea* Mart.) juice. *J Food Eng* 94:215–222
- Vulic J, Canadanovic-Brunet J, Cetkovic G, Tumbas V, Djilas S, Cetojevic-Simin D, Canadanovic V (2012) Antioxidant and cell growth activities of beet root pomace extracts. *J Funct Foods* 4:670–678
- Walton DE, Mumford CJ (2000) The morphology of spray dried particles a quantitative view. *Dry Technol* 18:1945–1986