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Effect of whey protein concentrate as drying aid and drying parameters on physicochemical and functional properties of spray dried beetroot juice concentrate

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A B S T R A C T

Beetroots are good source of functional betalain pigment inherent with antioxidant activity and TPC. The feasibility of spray drying was devised along with the effects of whey protein concentrate (WPC) (5–15%), inlet air temperatures (160–180 °C) and feed flow rate (400–600 ml/h) to produce powder from beetroot juice concentrate (BJC). The total solids content of BJC was adjusted to 25% (w/w) with the addition of WPC. The obtained powders were analyzed for powder yield, moisture content, hygroscopicity, bulk density, a-value (color), antioxidant activity (AOA), TPC, and betalain content. The results revealed that increasing inlet temperature lowered the bulk density, AOA, TPC and betalain content in terms of 0.590 to 0.482 g/ml, 74.75 to 68.85%, 22.23 to 19.36 mg GAE/100 g and 268.54 to 267.45 mg/100 g. Depending on the analysis of the results, inlet air temperature, WPC concentration, and the interaction among them had a significant effect on the studied responses ($p < 0.0001$). Feed flow rate on contrary, showed non-significant effect.

1. Introduction

Growing trend in consumer demand for beetroot (*Beta vulgaris* L.), given their attractive color value, particularly used in ice cream, sherbet, yogurt, dry soft drink mixes, confectionery and soups (Henry, 1996) and health-promoting properties for use in commercial products especially those for endurance sports is well known. Extracted pigment (betalains) is good for health since they have numerous beneficial effects associated with their anti-mutagenic (Edenharder, Sagr, Glatt, & Muckel, 2002) and antioxidant properties. The role of betalains as food-coloring agents is very well established in food industry. However, stability is an important aspect to consider for the use of these pigments as antioxidants and colorant in food, so spray drying is used to avoid colorant degradation.

Spray drying is a unanimously used microencapsulation technology, employed to produce commercial (Kha, Nguyen, & Roach, 2010) engineered powders from liquid (milk, fruits and vegetables juices) feed stocks in a single step (Quek, Chok, & Swedl, 2007). It offers short contact times and relatively low temperatures, allowing some properties of foods such as flavor, color, and nutrients, to be retained in substantial percentages. But the powders obtained by spray drying are amorphous materials, susceptible to glass-transition-related changes, including stickiness, caking, and collapse, as well as color changes (Bhandari, Datta, & Howes, 1997), leading to low product yield and operational problems.

A major part of these problems can be solved by the addition of some drying aid, like polymers, macromolecules and gums, to the feed before being atomized. Surface modification of droplets with protein is a novel way to minimize stickiness in sprays dried powder. Whey, major by-product from dairy industry, has good emulsifying properties and plays a protective role against thermal effects (Bernard, Regnault, Gendreau, Charbonneau, & Relkin, 2011). Whey protein concentrate (WPC) form smooth and non-sticky films or shells much earlier than other drying aid resulting higher recovery of powders in a small amount of proteins being spray dried (Bhusari, Muzaffar, & Kumar, 2014). The elementary operational conditions of spray drying namely temperature of drying air and feed flow rate of feed are crucial in explaining the quality characteristics of product. Therefore, it is important to optimize the drying process along with concentration of drying aid, in order to obtain products with better powder yield and nutritional characteristics. Hence, the objective of this work was to study the influence of inlet air temperature, feed flow rate and WPC concentration on powder yield, moisture content, hygroscopicity, bulk density, 'a' value (color), antioxidant activity, TPC and betalains content during the spray drying of BJC.

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2. Materials and methods

2.1. Materials

The chemicals Folin Ciocalteu reagent, gallic acid (GA), sodium carbonate was purchased from Loba Chemie Pvt. Ltd., (Mumbai, India); 2,2-diphenyl picryl hydrazyl (DPPH) purchased from Fluka Goldie, (Mumbai, India); Acetone, methanol (HPLC grade), Potassium nitrate (KNO_3) purchased from Ranbaxy, (New Delhi, India). WPC was procured by Nutrimed Healthcare Pvt. Ltd. (New Delhi, India).

2.2. Preparation of feed suspension for spray drying

Beetroots purchased from a local grower of Sangrur (Punjab, India), were well washed, sliced and juice elaboration was done. The feedstock in conventional large scale spray dryer is normally concentrated to 50–60% (w/w) before introduction to spray dryer. However, the small scale laboratory spray dryer will have more diluted feedstock because atomizer will be clogged easily if the feed has high viscosity (Murugesan & Orsat, 2011).Therefore, beetroot juice was concentrated and then optimized to 22% soluble solids at a temperature of 55 °C, on the basis of some functional properties viz. a-value, antioxidant activity, TPC and betalain content. Before feeding to spray dryer, WPC was added to BJC on total solid basis and feed was thoroughly blended for complete dissolution.

2.3. Spray drying

The suspension was provided to laboratory scale co-current spray dryer S.M. Scientech's (Kolkata, India) main chamber (500 mm × 215 mm) through a peristaltic pump and a 0.5 mm inner diameter nozzle and the feed flow rate was controlled by the pump rotation speed. The operational conditions of the drying process were inlet air temperature and feed flow rate which were ranged between 160–180 °C and 400–600 ml/h respectively according to applied experimental design. The outlet temperature was kept just half to the inlet air temperature. Powder was collected in an insulated glass bottle connected at the end of cyclone after drying and packed in polyethylene pouches and stored in a desiccator containing silica gel at 25 °C till it was further analyzed.

2.4. Physicochemical properties

Difference in amount (g) of total solids between resulting powder and feed suspension was used for calculating powder yield for spray drying. Powders moisture content was determined gravimetrically by drying in a vacuum oven at 70 °C until constant weight (AOAC, 1990).

2.4.1. Hygroscopicity

Hygroscopicity was determined according to the method proposed by Cai and Corke (2000) proposed with some modifications. Samples of each powder (approximately 1 g) were placed at 25 °C in a container with NaCl saturated solution (75.29% RH). After one week, samples were weighed and hygroscopicity was expressed as gram of adsorbed moisture per 100 g dry solids (g/100 g).

2.4.2. Bulk density

The bulk density (g/ml) of the samples was determined by placing 2 g of powder in a 10 ml graduated cylinder and calculating the volume from the scale (Ozdikicierler, Dirim, & Pazir, 2014).

$$\text{Bulk density} = \frac{\text{Mass of powder}}{\text{Volume}} \tag{1}$$

2.4.3. a^*-value

The powder color was determined by using CIE color lab Minolta chroma meter (CR-400; Minolta Corp, Japan). The a^* (green/red) value was measured in triplicates and mean value was reported.

2.5. Functional properties

2.5.1. DPPH radical scavenging activity

The antioxidant activity was evaluated by the chain-breaking reaction (Luo, Zhao, Yang, Shen, & Rao, 2009) using the stable free radical 2,2-diphenyl-1-picryl hydrazyl (DPPH$^\cdot$). The sample mixture with methanolic DPPH$^\cdot$ solution (1 mM) was shaken vigorously and then left to stand for 30 min in the dark. The absorbance was measured at 517 nm using DR 6000 UV–vis spectrophotometer (Colorado, USA). The absorbance of control was obtained by replacing the sample with methanol. DPPH$^\cdot$ radical scavenging activity of the sample was calculated as follows:

$$\text{DPPH radical scavenging activity}\,(\%) = [(A_{control} - A_{sample})/A_{control}] \times 100 \tag{2}$$

where $A_{control}$ is the absorbance of control and A_{sample} is the absorbance of sample.

2.5.2. TPC

Total Phenolic Content (TPC) was determined using the Folin–Ciocalteu reagent according to Singleton and Rossi (1965) with some modifications. A calibration curve was done with gallic acid as standard. The results were expressed as gallic acid equivalents in milligrams per 100 g of dry matter (mg GAE/100 g of dm).

2.5.3. Betalain quantification

Betalain content after drying were calculated according to Janiszewska (2014).

$$\text{Betalain} = \frac{A \times DF \times MW \times 1000}{\varepsilon \times L} \tag{3}$$

where A is the absorption at 538 and 480 nm for betacyanins and betaxanthins respectively. DF is the dilution factor and L is the path length of the cuvette (1 cm). Molecular weights (MW) and molar extinction coefficients (ε) of betacyanin and betaxanthin are 550 and 308 g mol^{-1} and 60,000 and 48,000 L mol^{-1} cm^{-1} respectively.

2.6. Experimental design

Box Behnken design was used for spray drying of BJC, considering three independent variables: inlet air temperature (160, 170 and 180 °C), feed flow rate (400, 500 and 600 ml/h) and WPC concentration (5, 10 and 15%). A total of 17 experiments were conducted including the central point (Khuri & Cornell, 1996) (Table 1). The responses were analyzed by using second order polynomial (SOP) model:

$$Y_k = \beta_{k0} + \sum_{i=1}^{n} \beta_{ki} x_i + \sum_{i=1}^{n} \beta_{kii} x_i^2 + \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \beta_{kij} x_i x_j \tag{4}$$

where Y_k=response variable; Y_1=powder yield (%); Y_2=moisture content (%); Y_3=hygroscopicity (g/100 g); Y_4=bulk density (g/ml); $Y_{5=}$a-value; Y_6=antioxidant activity (%); Y_7=Total phenolic content (mg GAE/100 g) and Y_8=Betalain content (mg/100 g); x_i represent the coded independent variables (x_1=temperature of inlet air, x_2=concentration of WPC and x_3=feed flow rate), where β_{ko}