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ORIGINAL ARTICLE

Effect of spray drying on physical properties of sugarcane juice powder (*Saccharum officinarum* L.)

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Abstract The aim of the present study was to investigate the spray drying behavior of sugarcane juice with (PSJ) and without (CSJ) citric acid the effects of different levels (10–50%) of carrier agents (maltodextrin (MD), Gum Arabic, liquid glucose and carrot fiber) at varying operating conditions of inlet and outlet temperature and feed concentration during spray drying was also studied. Spray dried powders from PSJ and CSJ were analyzed for physical properties such as wettability, cohesiveness, dispersibility, flowability, hygroscopicity, particle morphology etc. Different correlations between product recovery and operating conditions were obtained. Amongst the different carrier agents used maltodextrin (30%) proved to be the best in terms of sensory properties and product yield. Spray dried powder without citric acid (PSJ) proved to be superior in terms of porosity, flowability and other reconstitution properties with low hygroscopicity. Moreover PSJ powder revealed regular spherical shape with smooth surface and less agglomeration between particles.

Keywords Carrier agents · Drying yield · Enzymatic browning · Spray drying · Sugarcane juice

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Introduction

Sugarcane (*Saccharum* species hybrids) belongs to the grass family, Poaceae and is popular for its nutritious and refreshing juice (Singh et al. 2012). Sugarcane juice contains about 15% natural sugar and is rich source of vitamins, minerals, organic acids, amino acid, starch, gums and non-sugar phosphatides (Qudsieh et al. 2001). The juice is highly recommended for convalescing patients with jaundice, cancer and cardiovascular diseases making it an ideal refreshing health drink.

India is the second largest producer of sugarcane in the world and produced around 362 million ton sugarcane annually (FAO 2015). Despite having large potential for food and beverage industry, commercialization of sugarcane juice is restricted by immediate quality changes shortly after extraction. Presence of high amount of sugar, traces of polyphenols and organic acids coupled with high polyphenol oxidase activity causes quick fermentation and dark brownish appearance to the juice resulting in unmarketable juice (Qudsieh et al. 2002). Various techniques employed for preservation of sugarcane juice and minimizing quality changes, include heat inactivation of enzyme (Yusof et al. 2000), freeze concentration (Songsermpong and Jittanit 2010), blanching of raw materials in hot water or addition of antimicrobial and antioxidant agents (Ozoglu and Bayindirli 2002; Taylor 2005), low temperature storage and use of gamma radiation (2–10 kGy; Alcarde et al. 2001).

Spray drying technology is a viable alternative to conventional drying as it is rapid, economic and flexible. During spray drying, the feed from a fluid state (solution, dispersion or paste) is converted into a dried particulate form by spraying it through a hot drying medium. Spray drying involves a combination of processes namely atomization, mixing of spray and air, evaporation and product separation. The technology finds wide applications in food, chemical, and pharmaceutical industries. Preservation of various foods through spray drying has been reported, include tamarind (Cynthia et al. 2015), blackberry (Ferrari et al. 2012), bayberry juice (Fang and Bhandari 2012), non-dairy based probiotic drink (Mestry et al. 2011), bioactive compounds from pomegranate (Robert et al. 2010), and ginger juice (Phoungchandang and Sertwasana 2010). However there is no report on spray drying of sugarcane juice. Spray dried powders generally have good reconstitution characteristics, high flavor and sensory quality. These features qualify spray drying to be an ideal technology for commercialization of sugarcane juice for wider consumer market.

With lots of expediency spray drying imposes difficulty on account of stickiness of the final product in fruit juices with high sugar content due to low glass transition temperature and high hygroscopicity of some of the juice components (low molecular weight sugars and organic acids). This problem of stickiness can be overcome by addition of carrier agents, such as maltodextrin or gum arabic, to the feed solution before the atomization. Also, the carrier agents can protect sensitive food components against unfavorable environmental conditions (Bhandari et al. 1997).

Against this background, the aim of present investigation was to evaluate the effect of different encapsulating agents and spray drying parameters on physical properties of sugarcane juice powder.

Materials and methods

The sugarcane juice was extracted through commercial extractor and immediately transferred to ice box for maintaining temperature. The juice was divided into two lots, with or without citric acid which were designated as CSJ and PSJ respectively. The citric acid was added in different concentrations of 0.04, 0.1, 0.2 and 0.5% in juice and samples were coded as CSJ-0.04%, CSJ-0.1%, CSJ-0.2% and CSJ-0.5% respectively. Juice was filtered using double layered muslin cloth and stored at −20 °C until used. Based upon the color attributes, turbidity (Laksameethanasana et al. 2012) and sensory evaluation (9 point hedonic scale) the best sample (CSJ-0.1%) was optimized which was carried forward for spay drying experiments. Spray dried powder from PSJ served as control. Sugarcane juice had a total soluble solid content of 21.5°brix, with acidity of 0.158%, pH 4.885, specific gravity 1.0875, iron 112.97 mg/100 g, phosphorus 152.435 mg/100 g and potassium 25.36 mg/100 g.

Spray drying of sugarcane juice with carrot fiber and carrier agents

The frozen sugarcane juice was thawed, and feed solutions were prepared by addition of maltodextrin (DE 20), gum arabic, liquid glucose and carrot fiber. Carrot fiber was prepared by drying and grinding fresh carrots. The obtained carrot fiber was passed through sieve with ASTM no. 125, 0.125 mm and used as carrier agent. The carrier agents were tested in concentrations of 10 to 50% (w/w) of the sugarcane juice. The total solid content of all prepared solutions was fixed at 14.0 g/100 g and 100 g of solution was spray dried for each run. The solutions were fed into a laboratory tall type spray dryer (LSD-02-T) with a co-current air flow and two-fluid nozzle (inside diameter 0.5 mm) atomizer at a constant feed flow rate of 12 rpm keeping air pressure of 1.2 kg/cm^2 for atomization. The inlet and outlet air temperatures to be optimized were ranged between 140–160 °C and 90–105 °C respectively. The operation conditions were optimized to obtain best yield with different carriers. Spray dried powders from PSJ and CSJ-0.1% were collected from the product collection vessel and immediately packed.

Product yield and moisture content of powder

The product yield was calculated as the ratio of the amount of SJ powder collected after every spray drying experiment to the initial amount of solids in the feed solution. Powder samples were analyzed in quadruplicate for all tests. The moisture content of powder samples was determined gravimetrically by AOAC (2000) method.

Color attributes

Color attributes for PSJ and CSJ were evaluated using a Hunter color lab (Model no. A60-1012-312, Hunter associates laboratory, Reston, VA) in terms of CIE (Commission Internationale de L'Eclairage) 'L*' (lightness and darkness), 'a*' (redness and greenness) and 'b*' (yellowness and blueness). To start with, the sensor was calibrated with a black and white standard tile to measure the color. Color intensity (chroma), hue angle and total color difference (ΔE) between the samples were calculated (Duangmal et al. 2008).

Water solubility (WS) and water absorption index (WAI)

WAI was measured by dissolving 2.5 g of dry powder in 30 ml distilled water in previously weighed 50 ml centrifuge tube followed by intermittent stirring for 30 min at 30 °C and then centrifuging at 3000*g* for 10 min. The sediment left after pouring the supernatant into a tarred petri plate was weighed and WAI was calculated as ratio of wet sediment weight to dry sample weight (Medcalf and Gilles 1965).

For water solubility supernatant left after WAI experiment was dried overnight in hot air oven at 100 °C and dried solids obtained were weighed. WS was expressed as percentage of dried solids over initial dry sample weight (Schoch 1964).

Bulk and tapped density

Bulk and tapped densities for spray dried powders were determined by modified Goula et al. (2004) method. Bulk density was measured by transferring 2 g of powder to a 10 ml graduated cylinder and calculated as the ratio between the mass of powder and the volume occupied in the cylinder. For tapped density same cylinder was tapped on a bench for 100 times from a height of 10 cm and calculated by dividing mass of the powder with new volume occupied by the sample.

Porosity

Porosity (ε) of the powder samples was calculated using the relationship between the tapped and particle densities of the powder as given by Jinapong et al. (2008).

Flowability and cohesiveness

Flowability and cohesiveness of the powder were evaluated in terms of Carr index (CI) (Carr 1965) and Hausner ratio (HR) (Hausner 1967) respectively. Both CI and HR were calculated from the bulk and tapped densities of the powder as follows:

$$CI = [(\text{Tapped density} - \text{Bulk density})/\text{Tapped density}] \times 100$$

$$HR = \text{Tapped density}/\text{Bulk density}$$

Classification of the flowability and cohesiveness of the powder based on the CI and HR values are presented below:

Classification of powder flowability based on Carr index (CI)

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

Classification of powder cohesiveness based on Hausner ratio (HR)

HR	Cohesiveness
<1.2	Low
1.2–1.4	Intermediate
>1.4	High

Wettability and hygroscopicity

For wettability of spray dried powder, time taken for 5 g powder to submerge completely in 50 ml of distilled water at 25 ± 1 °C was determined (Gong et al. 2008).

Hygroscopicity was determined as the moisture absorbed by 5 g of the sample when placed in a desiccator at 21 °C and 76% RH using saturated NaCl solution (Al-Kahtani and Hassan 1990) and given as rate of moisture absorption (g water/kg dry solids/min) by dried powder.

Dispersibility

Dispersibility for spray dried powder was determined by modified A/S Niro atomizer method (1978) where 1 g powder was added in 10 ml distilled water into a 50 ml beaker at 25 ± 1 °C. The sample was then stirred vigorously with a spoon for 15 s making 25 complete movements back and forth across the whole diameter of the beaker. Then the reconstituted sugarcane juice was passed through a sieve with ASTM no. 212 (0.63 mm) and dried till constant weight obtained. Dispersibility was calculated using following formula:

$$\%\ \text{Dispersibility} = \{[(10 + a) \times \%TS]/a * (100 - b)\} \times 100$$

where a = amount of powder (g); b = moisture content in powder; %TS = dry matter in % in reconstituted sugarcane juice after it has been passed through the sieve.

Scanning electron microscopy (SEM)

Microstructure of the particles was evaluated through scanning electronic microscopy (Hitachi, S-3400 N, Japan). Powder samples were mounted on stubs using a double scotch tape and sputter coated with carbon. The ultrastructure of analysed samples was imaged under high vacuum conditions at an accelerating voltage of 30 kV.

Sensory evaluation

Sensory evaluation of juice and reconstituted spray dried powder was conducted based on 9 point hedonic scale for color, turbidity, consistency, aroma, intensity of taste, sweetness, sourness, mouth feel and overall likeness. A semi trained panel of 12 members was selected to evaluate the sensory profile. The sensory evaluation was performed in laboratory with clean sensory cabinets containing fresh water. The panelists were instructed to evaluate the above attributes of the samples and to rate each attribute. A nine point hedonic scale with 1 (dislike extremely), 5 (neither like nor dislike) and 9 (like extremely) was used.

Statistical analysis

All the experiments were carried out in quadruplicate and data were presented as mean with the standard deviation (SD). The data were analyzed statistically using SPSS software (SPSS PASW 18.0) and the means were separated using the Duncan's multiple range test ($p < 0.05$).

Result and discussion

Preprocessing of sugarcane juice: optimization of citric acid concentration

Prior to spray drying sugarcane juice was stabilized with citric acid in different concentrations to inhibit enzymatic browning. The results are presented in Table 1. Perusal of data shows that with increasing concentration of citric acid, values of L*, b* and hue (H°) increased while a* value decreased. This depicted that incorporation of citric acid in juice improved the color by increasing lightness and decreasing the redness. Total color difference (ΔE) with respect to PSJ showed a significant difference. The color difference (ΔE) ranged from 15.67 to 20.892 in CSJ samples. Improvement in color by addition of citric acid was due to the reduction of pH (pH < 4.5) and chelation of copper from the active site of enzyme leading to inhibition of polyphenol oxidase (PPO) activity and reduced enzymatic browning (Limbo and Piergiovanni 2007; Son et al. 2001).

Juice turbidity was significantly reduced in CSJ samples indicating higher juice clarity. Juice turbidity was due to the presence of colloids and suspension materials such as waxes, proteins, pentosans, gums, starch, silicate and soil particles. Turbidity is expressed in terms of absorbance. Lower the absorbance, lower is the turbidity. Our results were in agreement with the study of Laksameethanasana et al. (2012) and Chauhan et al. (2002). On the addition of organic acid, colloidal matters such as pectins, hemicelluloses, proteins and colored compounds were absorbed by the precipitated ions (formed by organic acid) and got separated from juice during filtration leading to decrease in turbidity.

Based upon overall acceptability (Fig. 1a) CSJ-0.1% was optimized for stabilization of the sugarcane juice.

Process optimization of spray drying

The operating conditions of spray drying process for sugarcane juice were optimized based on percentage yield after performing 62 runs with different carrier agents at different processing conditions. Preliminary lab experiments were performed to fix the range of drying parameters to be optimized such as percentage of carrier agent, inlet drying air temperature (IT), outlet drying air temperature (OT) and total soluble solids of the feed (data not shown).

Addition of carrier agents to the juice prior to spray drying showed a positive effect on yield of the dried product which is related to increase in the *Tg* (glass transition temperature) values of the amorphous fractions in the feed. This was in agreement with the results of Papadakis et al. (2006) for raisin juice concentrate. Figure 1b (i–iv) shows the photographs of spray dried sugarcane juice powders using different carrier agents. Based on best product yield (Fig. 2a) and sensory evaluation (Table 2) of dried powders, maltodextrin at a concentration of 30% was optimized. Also an inlet air temperature of 150 °C, outlet temperature of 100 °C and solid concentration of 14% was found to be optimum for spray drying operation.

Table 1 Color values for different samples of sugarcane juice

Sample	Color value						Turbidity
	L*	a*	b*	Hue angle H°	Chroma	ΔE	
PSJ	17.9425 ± 3.312^{c}	7.275 ± 1.073^{a}	17.955 ± 2.588^{d}	75.492	19.373	–	1.786 ± 0.151^{a}
CSJ-0.04%	31.523 ± 4.776^{ab}	3.044 ± 3.297^{b}	24.52 ± 0.794^{c}	92.138	24.708	15.666	1.7025 ± 0.174^{b}
CSJ-0.1%	33.888 ± 0.308^{ab}	2.43 ± 0.464^{b}	25.23 ± 0.104^{bc}	93.887	25.34	18.183	1.576 ± 0.189^{bc}
CSJ-0.2%	34.343 ± 2.211^{a}	1.8 ± 0.901^{b}	25.72 ± 0.136^{bc}	95.55	25.778	18.951	1.528 ± 0.177^{bc}
CSJ-0.5%	34.738 ± 1.141^{a}	2.735 ± 0.762^{b}	29.523 ± 0.818^{a}	94.119	29.649	20.892	1.414 ± 0.17^{c}

Values are expressed as mean ± SD. Means having different letters within the same column differ significantly at $p < 0.05$ (n = 4)

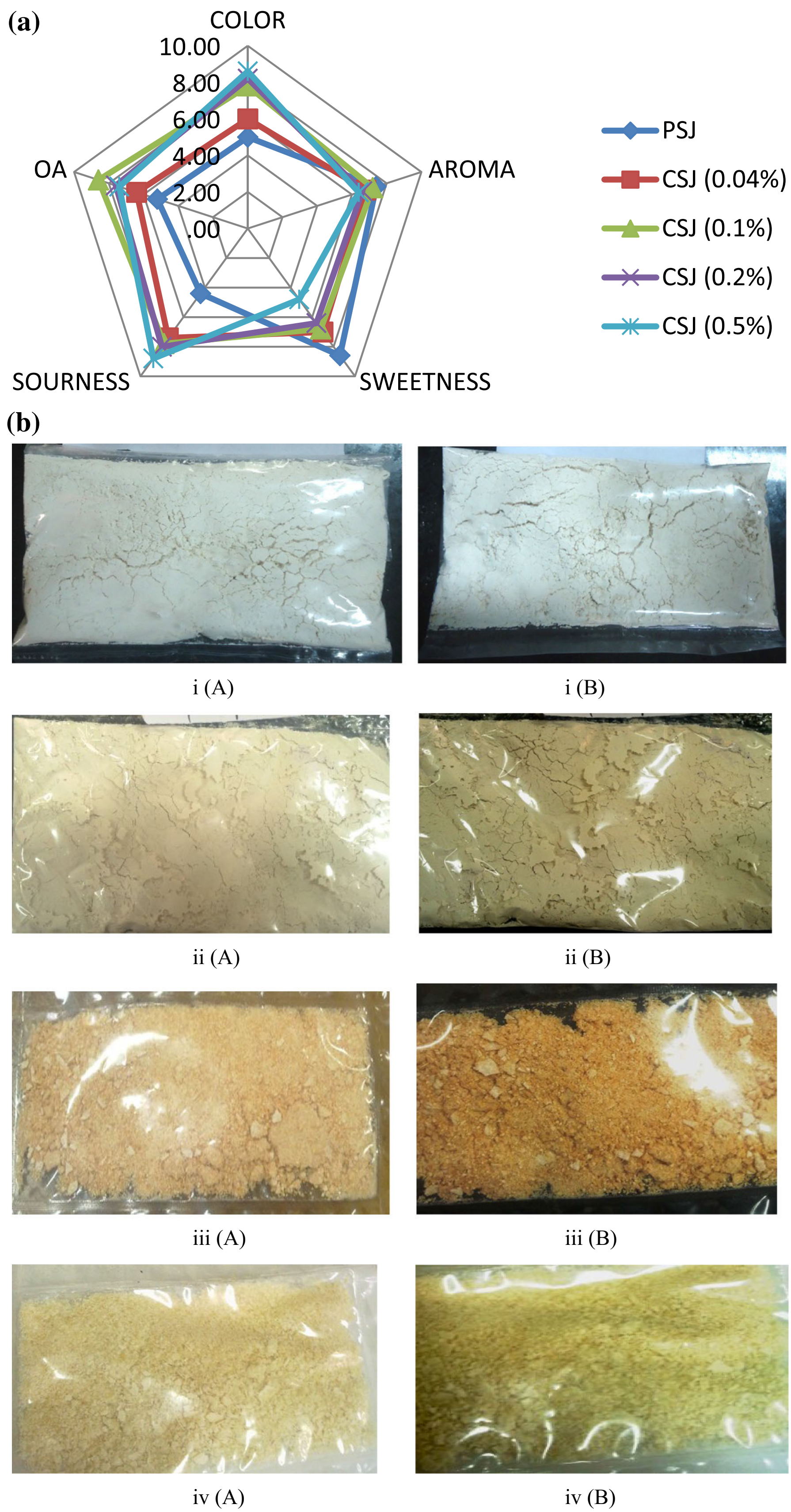
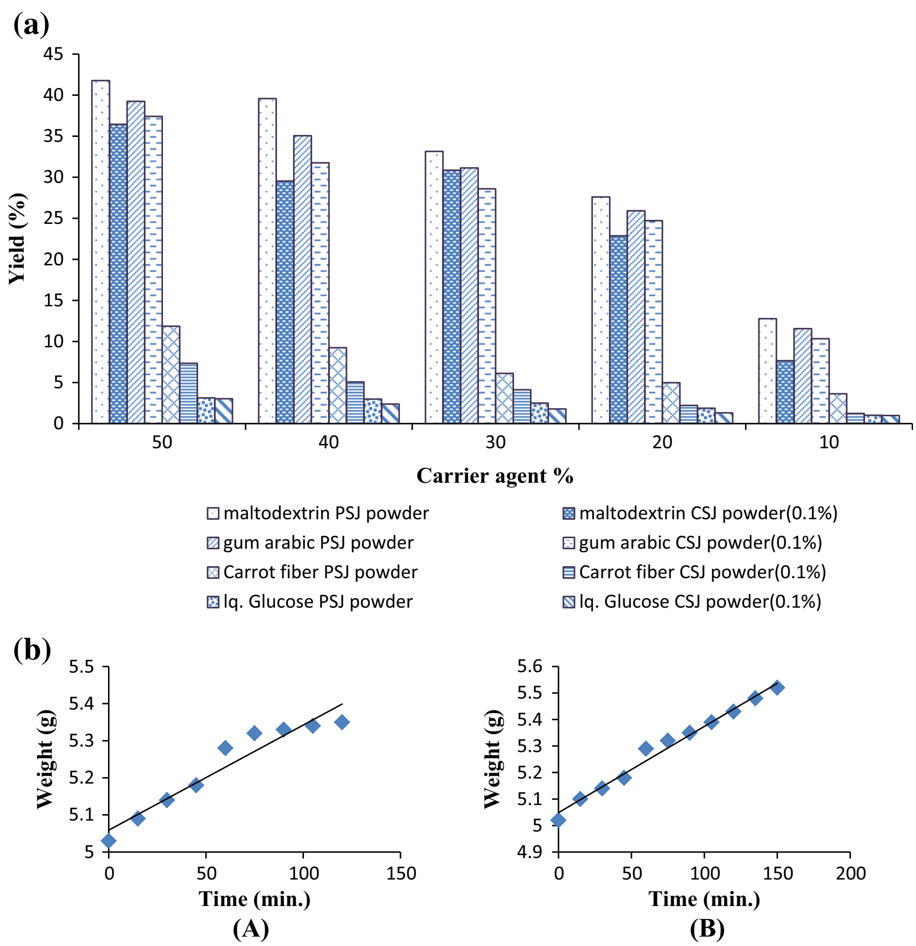


Fig. 1 **a** Sensory score for different juice samples for different parameters. **b** Spray dried sugarcane juice powder with different carrier agents (*i*–*iv*): (*A*) PSJ Powder (*B*) CSJ powder

Fig. 2 **a** %Yield for PSJ and CSJ-0.1% with different carrier agents **b** Relationship between increase in weight of powder with time for PSJ (*A*) and CSJ (*B*) powder



Physical properties of spray dried powder

Spray dried powders after recovery from collection vessel were compared with respect to various physical properties as discussed below. Table 3 shows the mean values and SD of the physical properties of PSJ and CSJ powders.

Moisture content

Moisture content is an important property of juice powder, which is related to the drying efficiency and affects shelf life stability of powder. Moisture content of sugarcane juice powders varied insignificantly from 3.24 to 3.02% for PSJ and CSJ-0.1% respectively (Table 3). Generally moisture content of commercially known spray dried powder is reported within this range (Quek et al. 2007).

Water solubility (WS)

Water solubility of powder indicates the ability of powder to dissolve in water. The values of WS for PSJ and CSJ powders in the present study were very high when compared to other spray dried powders (Abadio et al. 2004). However, WS of two samples was not influenced significantly by adding citric acid in juice. Result of water solubility showed high WS for PSJ sample (96.02%) than CSJ (95.90%) powder. These high values of WS for sugarcane juice powders may be due to low protein content of juice and therefore in powder. A similar observation was also reported by Jindal and Boonyai (2001) who stated that the quality of protein in any powder product is the main component that determine the powder solubility, because insoluble materials are formed during protein denaturation.

Water absorption index (WAI)

WAI is one of the instant properties of a powder represent the ability of a sample to reassociate with water under limited water conditions. An ideal powder intended for rehydration, would wet quickly and thoroughly, and sink rather than float. As shown in the present study WAI ranged between 0.178 and 0.203 for PSJ and CSJ powder respectively. Statistical analysis showed that there was no significant difference imposed by addition of citric acid on

Table 2 Sensory evaluation for juice and spray dried powder

Parameters	Sample					
	PSJ (control)	CSJ (0.1%)	Reconstituted sugarcane juice powder with different carriers			
			PSJ powder	CSJ-0.1% powder	Gum Arabic-PSJ powder	PSJ powder 60:40 (Juice: Maltodextrin)
Appearance						
Color	5.25 ± 2.598[b]	7.5 ± 1.243[a]	6.083 ± 1.975[ab]	5.917 ± 1.929[b]	2.67 ± 1.073[c]	5.83 ± 1.801[b]
Turbidity	5.583 ± 2.429[a]	6.917 ± 1.311[a]	6.25 ± 1.865[a]	6.167 ± 1.642[a]	3.92 ± 1.311[b]	5.33 ± 1.875[ab]
Consistency	7.833 ± 1.193[a]	7.667 ± 0.778[a]	6.083 ± 1.832[b]	6 ± 1.477[b]	5.67 ± 1.073[b]	5.83 ± 1.801[b]
Aroma	6.583 ± 2.065[a]	7.25 ± 1.603[a]	5.75 ± 2.137[ab]	5.833 ± 1.85[ab]	2.75 ± 1.215[c]	5.08 ± 1.85[b]
Taste						
Intensity	7.917 ± 0.9[a]	7.333 ± 1.303[a]	5.667 ± 2.188[b]	5 ± 1.907[b]	3.5 ± 1.624[c]	4.83 ± 1.801[bc]
Peculiar taste of sugarcane juice	7.5 ± 1.243[a]	7.333 ± 1.923[a]	5.25 ± 2.417[b]	4.917 ± 2.644[b]	2.25 ± 1.055[c]	4.5 ± 1.784[b]
Sweetness	7.917 ± 1.443[a]	7.917 ± 1.165[a]	5 ± 1.414[b]	4.917 ± 2.151[b]	4.67 ± 1.614[b]	4.5 ± 1.243[b]
Sourness	4.167 ± 1.749[bc]	5.833 ± 1.749[a]	4.75 ± 1.765[ab]	5.333 ± 2.348[ab]	2.58 ± 1.24[d]	3.25 ± 1.215 [cd]
Off taste (cooked or any other)	7.5 ± 1[a]	7.167 ± 1.193[a]	5.083 ± 1.881[b]	5.417 ± 1.975[b]	2.5 ± 1.243[c]	4.58 ± 1.24[**b**]
Overall taste	7.417 ± 1.621[a]	7.917 ± 0.996[a]	5.417 ± 1.929[b]	5.167 ± 2.082[b]	2.42 ± 0.793[c]	4.83 ± 1.467[b]
Mouth feel						
After taste	7.417 ± 1.311[a]	7.333 ± 1.231[a]	5.833 ± 1.801[b]	5.25 ± 1.815[b]	2.75 ± 1.357[c]	4.83 ± 1.115[b]
Particle remaining	7.667 ± 0.888[a]	8.083 ± 0.669[a]	7.417 ± 1.165[ab]	7.75 ± 1.055[a]	6.17 ± 0.718[c]	6.83 ± 1.03[bc]
Overall mouth feel	7.583 ± 1.165[a]	8.25 ± 0.754[a]	6.167 ± 0.937[b]	6.083 ± 1.729[b]	2.67 ± 1.231[c]	5.42 ± 0.793[b]
Overall acceptance	7.333 ± 1.826[a]	8.083 ± 1.084[a]	5.583 ± 1.975[b]	5.583 ± 2.275[b]	2.17 ± 0.835[c]	4.42 ± 1.379[b]

Values are expressed as mean ± SD. Means having different letters within the same row differ significantly at $p < 0.05$ (n = 12)

Table 3 Physical properties of spray dried powders

Parameter	Sample	
	PSJ powder	CSJ-0.1% powder
1. Moisture content(%)	3.24 ± 0.489[a]	3.02 ± 0.368[a]
2. Water solubility (WS) (%)	96.025 ± 3.906[a]	95.90 ± 2.6[a]
3. Water absorption index (WAI)	0.178 ± 0.038[a]	0.203 ± 0.055[a]
4. Bulk density (g/ml)	0.33 ± 0.0089[b]	0.357 ± 0.0031[a]
5. Tapped density(g/ml)	0.462 ± 0.0241[b]	0.508 ± 0.0257[a]
6. Porosity (ε)	74.015 ± 1.989[a]	70.315 ± 0.834[b]
7. Flowability	13.175 ± 3.295[a]	15.05 ± 2.483[a]
8. Cohesiveness	1.401 ± 0.111[a]	1.421 ± 0.069[a]
9. Wettability (s)	144.25 ± 26.663[b]	519.25 ± 150.087[a]
10. Dispersibilty (%)	89.605 ± 1.493[a]	89.268 ± 3.866[a]
11. Particle size (μm)	1.84 ± 0.105[a]	1.52 ± 0.125[b]

Values are expressed as mean ± SD. Means having different letters within the same row differ significantly at $p < 0.05$ (n = 4)

WAI (Table 3). However CSJ powder showed a slight increase in WAI. This finding is supported by the study of Ahmed et al. (2010) who stated that particles that would contribute to a higher WAI subsequently decreased the water solubility of samples or vice versa.

Bulk density and Tapped density

Bulk and tapped density are important indicator of transport cost, packaging considerations, as well as color density of the product and are well correlated with moisture content, particle size, and particle shape. High moisture content of PSJ powder (Table 3) resulted in lower bulk density. This observation is explained by Masters (1997); Goula et al. (2004) who suggested that at high temperature thermoplastic agglomerates formed which cause a decrease in powder moisture and increase in bulk density and vise a versa. Further, denser smaller particles of CSJ powder resulted in high bulk density (Goula et al. 2004).

Bulk and tapped density are directly correlated with each other and the value of tapped density is always higher than the bulk density. As shown in Table 3, values for tapped density showed significant difference among the powders at 5% level of significance. A high tapped density of CSJ powder was observed owing to high bulk density of same.

Porosity

Porosity in the powder is the result of occluded or absorbed gases present in liquid feed. According to Goula and Adamopoulos (2008), carrier agents also contribute to porosity by forming a covering and entrapping air inside the particle and thereby causing particle to become less dense and porous. Result for porosity indicates that porosity for PSJ powder (74.015) was significantly ($p < 0.05$) higher than the porosity of CSJ powder (70.315; Table 3). This is related to the fact that porosity and bulk density are interlinked. A powder with higher bulk density has less inter granular porosity which is the effect of size enlargement. Also with increase in particle size, the cohesivity of powder is expected to decrease (Jinapong et al. 2008) which leads to increase in porosity. Therefore, large particle size and lower bulk density of PSJ powder leaded to high porosity.

Flowability and cohesiveness

Flowability and cohesiveness are two important handling properties of dried particles. The combined effect of process parameters on flowability is usually expressed as the Carr index and the cohesiveness property is expressed as the Hausner ratio. Lower Carr index gives better desirable flowability and higher Hausner ratio indicates greater undesirable cohesiveness (Jinapong et al. 2008). Flowability is influenced by atomization pressure, particle geometry (spherical particles flow best) and density (higher density gives better flowability; Reineccius et al. 2004).

Although from statistical analysis it was reported that flowability and cohesiveness of two samples (13.175, 15.05; 1.401 and 1.421 for PSJ and CSJ powder respectively) were significantly same ($p < 0.05$; Table 3) but after comparison of individual value for both with standard value of CI and HR it was found that flowability of PSJ powder is good as compare to CSJ powder. Also for cohesiveness it was seen that PSJ powder had intermediate cohesiveness while other one has high. This poor flowability of CSJ powder could be due to smaller size of particles (Table 3) which resulted in exposure of large surface area per unit mass of powder for cohesive forces, in particular, and frictional forces to resist flow in CSJ powder (Fitzpatrick et al. 2004).

Wettability

Wettability is expressed as time in seconds, necessary for a given amount of powder to penetrate the quiet surface of water i.e. ability of a powder to absorb water on the surface and get wet. Moreover, wettability is a function of moisture content and particle size. As concluded from the results, high moisture content and large particle size of PSJ powder makes it highly wettable (144.25 s) when compared to CSJ powder (519.25 s; Goula et al. 2004).

Hygroscopicity

Hygroscopicity is the capacity of powders to adsorb ambient moisture and given as the rate of moisture absorption in g of water/kg dry solids/min. Furthermore, hygroscopicity of juice powder is affected by moisture content and is in indirect correlation with powder moisture (Goula et al. 2004). The variation in moisture content of PSJ and CSJ powder resulted in small insignificant difference in water absorption capacity of the powders (Table 4). Although, there was no clear pattern observed for the increase in weight of the powder with time i.e. in hygroscopicity for both samples (Fig. 2b). Data showed that for the first 2.5 h of the hygroscopicity test, the increase in weight for CSJ powder was directly proportional to the time. A similar trend was also observed for PSJ powder but only up to first 2 h. Further, high sugar content of sugarcane juice powders resulted in highly hygroscopic dried product. Due to this, spray dried PSJ and CSJ powders turned into a light brown colored sticky mass at the end of the test after the exposure to a relative humidity of 76%. Same result was reported by Papadakis et al. (2006) for raisin juice powder.

The following regression equations for PSJ (1) and CSJ (2) powders revealed a relationship between increase in weight of powder and time:

$$y = 0.0028x + 5.0589 \quad (1)$$

$$y = 0.0028x + 5.0589 \quad (2)$$

where, y denotes increase in weight of powder (g) and x is time in minutes.

Table 4 Variation in weight and hygroscopicity of powders with time

S. no.	Time (min)	Interval	Weight of powder (g)		Hygroscopicity (g of H_2O/kg dry solids/min)	
			CSJ-0.1% powder	PSJ powder	CSJ-0.1% powder	PSJ powder
1.	0	1st	5.02	5.03	1.06	0.795
2.	15	2nd	5.1	5.09	0.53	0.663
3.	30	3rd	5.14	5.14	0.53	0.530
4.	45	4th	5.18	5.18	1.461	1.33
5.	60	5th	5.29	5.28	0.398	0.53
6.	75	6th	5.32	5.32	0.398	0.133
7.	90	7th	5.35	5.33	0.53	0.133
8.	105	8th	5.39	5.34	0.53	0.133
9.	120	9th	5.43	5.35	0.664	–
10.	135	10th	5.48	–	0.53	–
11.	150	–	5.52	–	–	–
Mean ± SD					0.6631 ± 0.3319[a]	0.53088 ± 0.4142[a]

Values are expressed as mean ± SD. Means having different letters within the same row differ significantly at $p < 0.05$ ($n = 10$). One interval = 15 min

Coefficient of determination $R^2 = 0.924$ and 0.983 obtained for PSJ and CSJ powder respectively shows the goodness of fit for regression Eqs.(1) and (2) for depicting relationship between increase in weight of powder and time.

Dispersibility

Dispersibility is the ability of a powder to separate into individual particles when dispersed in water with gentle mixing. A high dispersibility value (89.605%) was obtained for PSJ powder. This could be comprehend by the fact that high moisture content and large particle size of powders leads to settling down and easy dispersion in water (Ghosal et al. 2010).

Morphological analysis of the sugarcane juice powders

SEM microstructures of spray-dried sugarcane juice powders are shown in Fig. 3a, b. Micrographs of spray-dried powder revealed spherical shape of particles with a high proportion of agglomerates indicating high hygroscopicity of both samples. However, more agglomeration was observed in CSJ powder probably due to presence of highly hygroscopic citric acid. Dented surface observed for spray dried particles of PSJ powder was attributed to the shrinkage of particles during drying. Similar morphology was observed in cactus pear powder by Saenz et al. (2009). Also, CSJ powder showed small particle size (1.52 µm) as compare to PSJ powder (1.84 µm) which contributes to variability in physical properties like bulk density, wettability, water solubility, flowability and cohesiveness of the powder.

Sensory evaluation

The sensory score for juice and powder samples are depicted in Table 2. Score for different parameters of sensory showed that control (PSJ) had lower acceptance for color, turbidity and sourness while it was mostly preferred for its consistency, intensity of taste, less or no off taste and acceptability after taste. However, the CSJ-0.1% sample has satisfactorily accepted for color, turbidity, aroma, sweetness, sourness, overall taste, particle absence, overall mouth feel and overall acceptance during the study.

GA-PSJ powder scored less for all parameter and on the basis of this PSJ powder with Gum Arabic was rejected. Both PSJ and CSJ powders (Fig. 3c, d) were significantly same for all parameters and after comparing their means for all sensory aspects the PSJ powder was found to be more acceptable as compared to CSJ. The comparison between powders with two concentration of maltodextrin i.e. 30 and 40% revealed that PSJ powder with 30% maltodextrin was more acceptable especially with respect to sweetness and overall taste this was probably due to high concentration of juice solids in this combination. Hence PSJ powder with 30% maltodextrin was optimized based on sensory scores.

Conclusion

This study proved spray drying as a promising economical tool for processing of sugarcane juice and converting it to a powder form which can further be processed into instant beverage by reconstitution. The spray drying parameters of

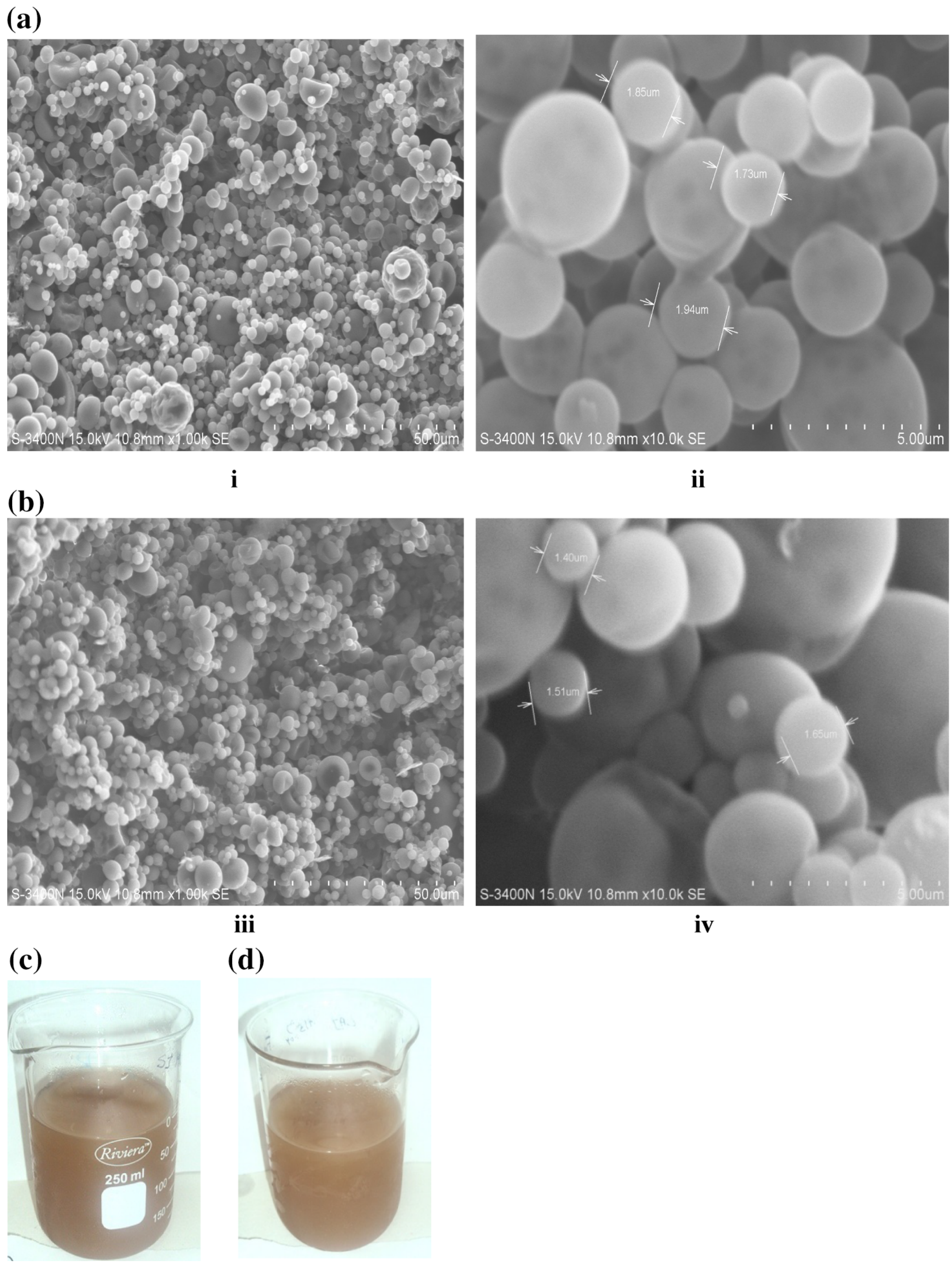


Fig. 3 **a** SEM image for PSJ powder with maltodextrin at ×1000 (*i*) and ×10000 (*ii*) **b** SEM image for CSJ powder with maltodextrin at ×1000 (*iii*) and ×10000 (*iv*) **c** Reconstituted spray dried PSJ powder **d** Reconstituted spray dried CSJ powder

inlet and outlet air temperature and sugarcane juice concentration were found to have profound effect on product yield. The optimum operation is obtained for inlet air temperature of 150 °C, outlet temperature of 100 °C and total soluble solids of 14°. The combined effect of added citric acid and spray drying parameters was observed on physical properties of sugarcane juice powders. Incorporation of citric acid, negatively influenced reconstitution properties of the spray dried powder. In respect to powder morphology, addition of citric acid resulted in particles with smooth surface and more agglomeration. Overall it can be concluded that spray drying is a viable technology for preservation of sugarcane juice and adoption of this technology could open up a new market opportunity for the sugarcane industry.

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