Agriculture and Natural Resources 50 (2016) 139–145

Contents lists available at ScienceDirect

Agriculture and Natural Resources

journal homepage: http://www.journals.elsevier.com/agriculture-and-natural-resources/

Original article

Investigation of suitable spray drying conditions for sugarcane juice powder production with an energy consumption study

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ARTICLE INFO

Article history:
Received 30 December 2014
Accepted 3 August 2015
Available online 9 June 2016

Keywords:
Drying aid
Energy cost
Spray drying
Sugarcane juice
Sugarcane juice powder

ABSTRACT

Sugarcane juice was spray-dried under various conditions to determine the most suitable drying conditions for the manufacture of sugarcane juice powder. Initially, fresh, 30°Brix and 50°Brix sugarcane juice samples were dried in a laboratory-scale spray dryer at an air-drying temperature between 130 °C and 170 °C using maltodextrin, Arabic gum and dietary fiber as drying aids. It appeared that sugarcane juice should be concentrated under vacuum to 30°Brix and added with at least 15% maltodextrin before drying at 170 °C in order to obtain dried powder product with a low drying cost. After conducting the experiments in the laboratory, sugarcane juice powders were produced in a factory using an industrial-scale spray dryer under five drying conditions. It was found that the energy cost of industrial-scale production of sugarcane juice powder ranged between 0.77 USD and 2.06 USD per kg of powder. According to the results of the industrial-scale experiments, the sugarcane juice powder should be produced using vacuum evaporation of the sugarcane juice to 30°Brix prior to adding maltodextrin at 30% by weight and then spray drying at 190 °C.

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Introduction

Sugarcane (*Saccharum officinarum* L.) is a vital crop in the world particularly for the tropical countries, with the majority of sugarcane being used for sugar and alcohol production (Sachs, 1980; Verheye, 2010). Sugarcane juice is popular in many countries due to its taste and low price (Songsermpong and Jittanit, 2010). Additionally, in Indian medicinal practice, it has been used to cure jaundice and liver-related disorders (Kadam et al., 2008). Hudson et al. (2000) and Hollman (2001) claimed that the flavonoids existing in sugarcane juice have abilities to protect cells from degenerative processes and to reduce the development of health problems such as cancer and cardiovascular diseases. Nevertheless, the marketing of sugarcane juice is limited due to its rapid deterioration in quality (Mao et al., 2007).

Processing sugarcane juice to powder is an interesting method to lengthen the product shelf life at ambient temperature and to reduce logistical expenditure. In addition, the powder is easy to use compared with squeezing the juice from the fresh sugarcane stem. Sugarcane juice powder can be consumed as an instant juice powder or as a flavoring agent. Sugarcane juice powder is dissimilar to the crystallized sugar generally available in the market in aspects of flavor, pigments, nutrients and physical properties due to different manufacturing techniques (Oliveira et al., 2007).

Although, to date there has been no published research on the production of sugarcane juice powder, a number of studies on fruit juice drying were found. Gabas et al. (2007) claimed that drying the fruit juice could produce a powder that reconstituted quickly to a product resembling the original juice. According to previous works, there are some difficulties in drying fruit juices that have a high sugar content due to thermoplasticity and hygroscopicity at high temperatures and humidities causing difficulties in packaging and utilization (Bhandari et al., 1997; Adhikari et al., 2004; Cano-Chauca et al., 2005). These characteristics are attributed to low molecular weight sugars such as fructose, glucose and sucrose and organic acids that are the major solids in fruit juices (Bhandari et al., 1997; Cheuyglintase and Morison, 2009). The low glass transition temperature (T_g), high hydroscopy, low melting point and high water solubility of these solids cause a highly sticky or rubbery product when dried (Adhikari et al., 2003; Cheuyglintase and Morison, 2009).

Adding some drying carriers such as maltodextrin (MD) and Arabic gum (AG) into the feed usually overcomes the thermoplasticity and hygroscopicity troubles (Bhandari et al., 1993; Cano-

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http://dx.doi.org/10.1016/j.anres.2015.08.003

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Chauca et al., 2005; Gabas et al., 2007). These drying adjuncts are high molecular weight compounds that have high T_g; accordingly, they can raise the T_g value of the feed and the subsequent powder (Shrestha et al., 2007). According to Cano-Chauca et al. (2005) and Langrish et al. (2007), MD is the most popular adjunct in spray drying due to its physical properties such as high water solubility; AG is recommended for fruit juice drying due to its emulsification properties and because it dissolves easily in water.

Spray drying is a technique commonly used in the food industry to make food powder due to its effectiveness under optimum conditions (Cano-Chauca et al., 2005). Spray drying parameters such as the drying air temperature and the feed rate are influential regarding the attributes of spray-dried food such as color, particle size, bulk density, moisture content, nutrient retention, average time of wettability and the amount of insoluble solids (Greenwald and King, 1981; Welti and Lafuente, 1983; Chegini and Ghobadian, 2005; Fazaeli et al., 2012).

Due to the lack of research on the spray drying of sugarcane juice, this study was carried out with the following objectives: 1) to study the feasibility of producing spray-dried sugarcane juice powder; 2) to determine suitable drying conditions for spray drying sugarcane juice; and 3) to compare the product quality between various drying carriers and to estimate the energy cost of industrial-scale production of sugarcane juice powder.

Materials and methods

Raw materials

Fresh sugarcane juice squeezed from freshly harvested sugarcane of the “Suphanburi 50” variety was obtained at the local market nearby Kasetsart University, Bangkok, Thailand. The fresh sugarcane juice was used for preparing concentrated sugarcane juice of 30°Brix. The concentrated juice samples were produced using a laboratory-scale vacuum evaporator (model REV-T; Hisaka Works Co. Ltd.; Osaka, Japan). The sugarcane juice was heated using hot water as a heating medium at a temperature of 70 °C and evaporated in the chamber under vacuum of 70 cm Hg. The system was operated until the juice concentration reached the level of 30°Brix.

Two sorts of drying adjunct (MD and AG) were primarily applied in this study. The MD had a dextrose equivalent (DE) 10–12, pH 4.7 and a moisture content of 5.2%. It was made by Zhucheng Dongxiao Biotechnology Co., Ltd. (Zhucheng city, Shandong, China). The AG used in this work was KB-120 (food grade), which had a pH (25% solution in water) of 4.4 and a moisture content of 11.8%. It was supplied by Lab Valley Limited Partnership (Bangkok, Thailand).

Drying experiments

The feed materials were prepared by adding the specified amount of drying carriers into the concentrated sugarcane juice samples of 30°Brix and then stirring. The ratios by weight of juices (30°Brix) and MD at 1:0.1 and 1:0.15 were applied whereas those of juices (30°Brix) and AG were 1:0.05, 1:0.1 and 1:0.15. These figures can be converted to ratios between the weight of total soluble solid in sugarcane juice and the dry weight of drying aid as shown in Table 1.

The feed materials were dried in a small-scale spray dryer (Mobile Minor 2000, GEA Process Engineering; Soeborg, Denmark). The schematic diagram of the dryer is shown in Fig. 1.

The drying conditions applied in this study are summarized in Table 2. The feed rate was maintained at 0.022 L/min for all drying runs. At the end of drying, the sugarcane juice powders were collected, weighed and kept in sealed containers for quality determination.

Quality determination

The color and pH of the fresh sugarcane juice after standardization to 12°Brix were measured using a colorimeter (model CM-3500d; Konica Minolta Sensing, Inc.; Osaka, Japan), and a pH meter. The sugarcane juice powder samples collected from the drying runs were measured for their bulk density, moisture content, water activity and solubility. In addition, the reconstituted samples of sugarcane juice powder were determined for color, pH and the percentage of insoluble solid. All quality attributes were determined in three replications.

Bulk density determination

The procedure described by Al-Kahtani and Hassan (1990) was applied. Samples of 20 g of powder were put into a 100 mL graduated cylinder which was mounted on the shaker compartment of a water bath (model Stuart Scientific SBS 30; Bibby Scientific Ltd.; Stone, UK). The shaker was operated at 100 revolutions/min for 5 min. The bulk density was calculated by dividing the weight of the powder by the volume occupied in the cylinder.

Moisture content determination

The moisture content of powder was determined using the oven method with 2 g of powder and drying at 105 °C for 2 h. Subsequently, each sample was cooled in a desiccator, weighed and redried for 2 h. The process was repeated until the change in weight between successive drying cycles at 2 h intervals was not more than 2 mg (Jittanit et al., 2010). The weight loss after drying in the oven was used to calculate the moisture content of the powder and was expressed on a wet basis (wb).

Water activity measurement

The water activity of sugarcane juice powder was measured using a thermoconstanter (model TH2/RTD33; Novasina AG; Lachen, Switzerland).

Determination of solubility

To determine the solubility of powder, the method of Al-Kahtani and Hassan (1990) was applied. Each powder sample (10 g) and distilled water (100 mL) were put into a 500 mL beaker. Then, a magnetic bar was added and the beaker was placed on a stirrer (model 210T; Fisher Scientific (M) Sdn Bhd; Selangor Darul Ehsan, Malaysia) at a speed level setting of 5. Measurement was conducted at room temperature (25 °C). The time for the powder in the beaker to be completely dissolved was recorded in seconds and then converted into decimal minutes.

Color and pH measurement for reconstituted samples

The powder samples were dissolved in distilled water to prepare reconstituted samples that had a soluble solid content of 12°Brix. The color of reconstituted samples was measured and expressed as L^*, a^* and b^* values in the CIE system (Francis, 1998). The color and pH of the reconstituted samples were measured and then compared to those of the fresh sugarcane juice.

Table 1
Ratio of sugarcane juice (30°Brix) and drying aid used in experiments.

Drying aid	Ratio by weight of juice and drying aid	Ratio between the weight of total soluble solid in juice and dry weight of drying aid
Maltodextrin	1:0.10	76:24
	1:0.15	68:32
Arabic gum	1:0.05	87:13
	1:0.10	77:23
	1:0.15	69:31

Table 2
Summary of drying conditions.

Run	Drying aid	Inlet drying air temperature (°C)	Ratio by weight of juice and drying aid
1	MD[a]	130	1:0.10
2	MD	150	1:0.10
3	MD	170	1:0.10
4	MD	130	1:0.15
5	MD	150	1:0.15
6	MD	170	1:0.15
7	AG[b]	150	1:0.05
8	AG	150	1:0.10
9	AG	150	1:0.15

[a] Maltodextrin.
[b] Arabic gum.

Determination of insoluble solid percentage

The percentage of insoluble solid was determined using the method of Vongsawasdi et al. (2002). Each powder sample (20 g) was dissolved in 200 mL of distilled water at room temperature. Then, the solution was filtered using a 2 L suction flask with a Büchner funnel (diameter 18.5 cm) and Whatman filter paper No 41. The suction flask was connected to a vacuum pump (model GLD-050, motor 200 W; ULVAC Technologies, Inc.; Methuen, MA, USA). The solid that could not pass through the filter paper was dried and weighed and used to calculate the percentage of insoluble solid (100 * mass of insoluble solid/mass of total solid).

Statistical analysis

The SPSS statistical software package (version 12.0; SPSS Inc.; Chicago, IL, USA) was used for ANOVA.

Drying experiment using dietary fiber as a drying aid

According to Cheuyglintase and Morison (2009), carrot fiber powder has a T_g comparable to MD and can be used as a drying carrier for spray drying of fructose and apple juice with a similar product appearance obtained from using MD. Thus, in this work, the sugarcane stems were passed through a rolling squeezer (Ngow Huat Yoo Machinery Co., Ltd.; Bangkok, Thailand) and then were ground in a grinder followed by drying in a hot air oven at 80 °C until the moisture content of the sample was lower than 5%. After that, the dried sugarcane fiber was ground again in the grinder before separating the fiber powder using a 100 mesh sieve in a vibratory sieving machine (model 880101; Brabender GmbH; Duisburg, Germany).

The fiber powder was used as a drying aid for the spray drying of 30°Brix concentrated sugarcane juice at a drying air temperature of 150 °C, feed rate of 0.022 L/min and a ratio of juice to drying aid of 1:0.05.

Industrial-scale drying test

After conducting the drying experiments using the small-scale spray dryer, seven additional experiments were carried out using an industrial-scale spray dryer (model SD-02; HVAC Engineering Co., Ltd., Pathum Thani, Thailand) with a maximum moisture evaporation capacity of 36 L/h to study the effect of scaling up the dryer and the energy cost for industrial-scale production of sugarcane juice powder. The schematic diagram of the dryer is shown in Fig. 2. The drying adjunct used in the industrial-scale drying test was MD as it had a much lower price than AG. The description of each industrial-scale drying run is presented in Table 3. For the sample preparation in the industrial-scale drying test, the fresh sugarcane juice (15°Brix) was concentrated to 30°Brix using an industrial-scale vacuum evaporator (HVAC Engineering Co., Ltd.,

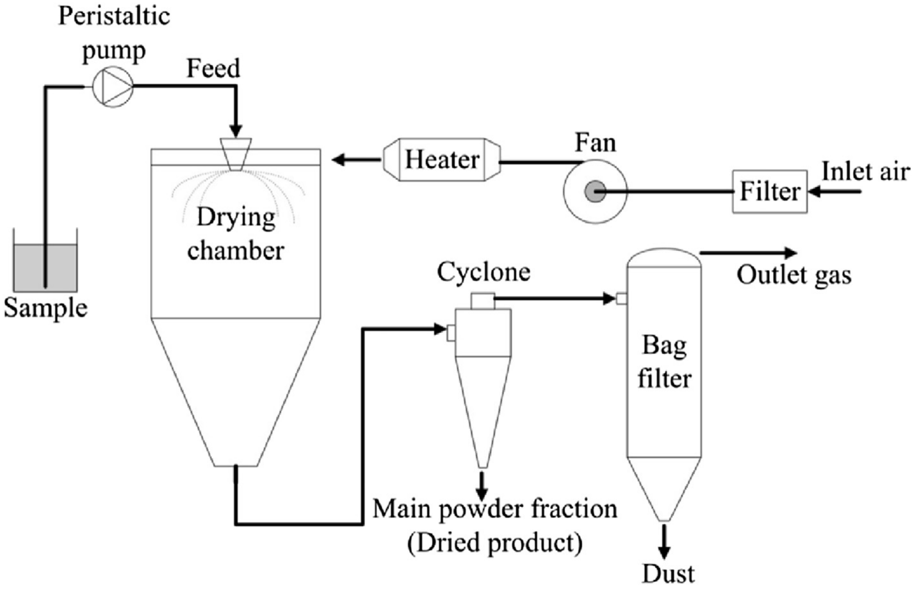

Fig. 1. Schematic diagram of the small-scale spray dryer.

Pathum Thani, Thailand) with a maximum moisture evaporation rate of 50 L/h. During concentration, the sugarcane juice was heated using hot water at 80 °C and evaporated in the chamber under a vacuum of 70 cm Hg.

Energy cost for the industrial-scale production

The energy cost for the production of sugarcane juice powder was estimated using the data from the industrial-scale drying test. The energy cost could be divided into two major parts comprising: 1) energy consumed during juice concentration; and 2) energy used during spray drying. It should be noted that the energy cost calculated in this study excluded the energy required for warming up the system.

Only electrical energy was consumed by both the juice concentration and spray drying systems in this test. The juice concentration system needed the electrical energy for the vacuum pump, feed pump, hot water pump, cold water pump, electrical heaters, motor for the rotating disk, fan and pump of the cooling tower and for the refrigeration unit of the ice bank. The spray drying system required the electricity for the peristaltic pump, fan and electrical heaters. The electrical energy consumption (EC, measured in megajoules (MJ)) and the electrical energy cost (EEC measured in US dollars, though all experimental cost data were originally in Thai baht and have been converted using 1 USD is approximately 35.29 Thai baht) were calculated using Equations (1) and (2), respectively. The unit price of electricity was approximately 0.09 USD per kWh (0.09 USD per 3.6 MJ of electrical energy).

$$\mathrm{EC} = 3.6 * P * t \tag{1}$$

$$\mathrm{EEC} = P * t * \mathrm{UPE} \tag{2}$$

where P is the electrical power of equipment (in kW), t is the period of time (in h) the equipment is used and UPE is the unit price of electricity (in US dollars).

Results and discussion

Drying experiments using small-scale spray dryer

After conducting all the drying experiments described in Table 2, it appeared that there were some drying conditions that could not provide suitably dried powder products. The sugarcane juice samples that were dried in drying runs 1–3 were not in powder form but rather were viscous and remained stuck inside the spray dryer because the concentrated sugarcane juice at 30°Brix clearly contained a large amount of low molecular weight sugars especially sucrose. Therefore, drying these juices without adding the sufficient ratio of drying adjuncts would result in products that were sticky due to the T_g, high hydroscopy, low melting point and high water solubility of sucrose (Adhikari et al., 2003; Cheuyglintase and Morison, 2009). Drying experiment 4 produced a sticky and agglomerated product instead of powder due to the drying temperature being too low leading to inadequate evaporated moisture from the product. Caramelization occurred when the sucrose with high remaining moisture was exposed to heat. Consequently, the sugarcane juice became a sticky paste like caramel. Drying runs 5 and 6 resulted in fine powder. According to the results just described, it appears that sugarcane juice powder can be manufactured by drying the feed mixture of 30°Brix sugarcane juice and MD (15% by weight of juice) at a drying temperature not lower than 150 °C. When considering drying runs 7–9, it was found that if the ratio by weight of 30°Brix sugarcane juice and AG was 1:0.1 or 1:0.15, the products from spray drying were powder as required. On the other hand, experiment 7 using a ratio of 1:0.05 resulted in a product with sticky characteristics for the same reasons attributed to runs 1–3.

Only the dried samples from four drying conditions (runs 5, 6, 8 and 9) were considered further for determination of their bulk density, moisture content, water activity and solubility because the samples from the other drying runs were not in powder form. The results are shown in Table 4 and indicate that all drying conditions except condition 5 provided sugarcane juice powder with no significant differences in their bulk density values which ranged between 0.513 g/mL and 0.625 g/mL. Bulk density is a vital attribute for packaging design and the calculation of transportation volume. The bulk density of the sugarcane juice powders was in agreement with those of orange powders produced by Chegini and Ghobadian (2005) that ranged from 0.34 g/mL to 0.95 g/mL. The drying temperature and the formula of feed are deemed as the causes of differences in the bulk density of powder product, as for the same formula of feed, a higher drying temperature resulted in a lower bulk density (Chegini and Ghobadian, 2005). The elevated drying temperature led to a higher rate of moisture evaporation from the feed and subsequently, a higher porosity and lower bulk density of the dried powder. Nathakaranakule and Prachayawarakorn (1998) and Jittanit (2011) pointed out that the higher drying temperature

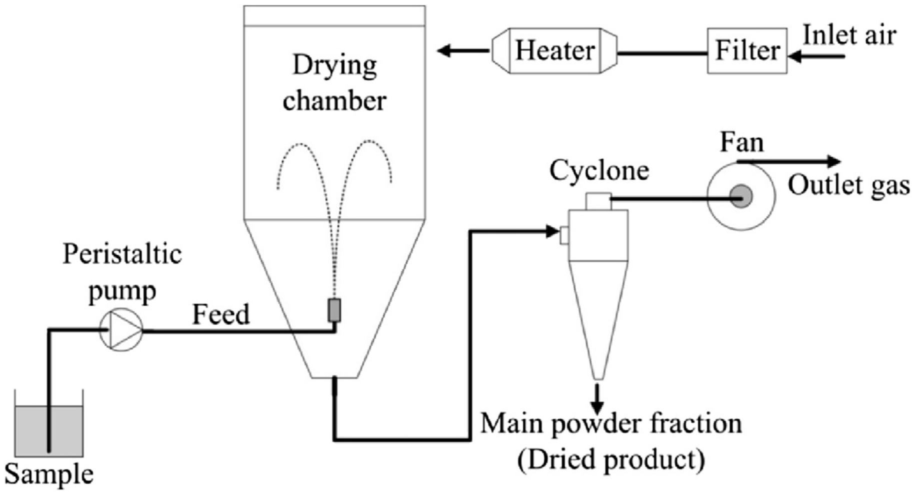

Fig. 2. Schematic diagram of the industrial-scale spray dryer.

Table 3
Conditions of all industrial-scale drying runs.

Run	Juice concentration (°Brix)	Inlet/outlet drying air temperature (°C)	Ratio 1[a]	Ratio 2[b]
1	30	150/70	1:0.15	68:32
2	30	170/80	1:0.15	68:32
3	30	190/90	1:0.15	68:32
4	30	190/90	1:0.20	61:39
5	30	210/100	1:0.20	61:39
6	30	180/90	1:0.30	51:49
7	15	180/90	1:0.15	51:49

[a] Ratio by weight of juice and drying aid (MD).
[b] Ratio between the weight of total soluble solid in juice and dry weight of drying aid.

resulted in a faster drying rate due to the elevated driving force for moisture transfer. Furthermore, at the same drying temperature, the higher proportion of AG would raise the bulk density of the powder because AG has a higher bulk density than sugarcane juice powder (referring to the specification data, the bulk density of AG was 0.64 g/mL).

All powder samples had moisture contents below 5% wb, which were similar to the moisture contents of dried tea powder and pineapple juice powder produced by other researchers (Sinija et al., 2007; Jittanit et al., 2010, respectively). With the same formula of feed, the higher drying temperature resulted in a lower moisture content of dried product since the heat and moisture transfer rates are usually enhanced if the drying temperature is raised (Nastaj, 2000; Vongsawasdi et al., 2002). The water activities of powders ranged between 0.198 and 0.241 which were low enough for long-term storage. Moreover, it appeared that the powders produced using MD as a drying adjunct had a lower moisture content than those using AG due to the higher initial moisture content of AG (approximately 11.8%) than that of MD (approximately 5.2%). Furthermore, the AG might have had higher water binding capacity than MD resulting in less moisture evaporation during drying.

The solubility values of the sugarcane juice samples ranged between 0.75 min and 1.33 min indicating that the powder could be dissolved in water at room temperature without difficulty; therefore, it would be convenient to use in practice. The reason for these solubility values is that the majority of the sugarcane juice powders are sucrose and the drying carriers are easily dissolved in water. Furthermore, the high drying temperatures applied in the spray dryer had a positive effect on solubility because these temperatures resulted in high porosity of the powders and subsequently a greater specific surface area of the powder. The specific surface area is directly related to the contact surface area between powder and water during dissolution.

As previously described, the reconstituted samples from the sugarcane juice powders were tested for their color, pH and percentage of insoluble solid. The quality attributes of the reconstituted samples are compared with those of fresh juice in Table 5. The results showed that the lightness (L^*) of the reconstituted samples from powders applying MD as the drying aid was higher than that of powders using AG but not significantly ($p > 0.05$) different from the fresh juice. The a^* values of the reconstituted samples were between −0.61 and 1.69. The a^* values of the reconstituted samples from powders applying MD as the drying aid were closer to those of the fresh juice than those from powders applying AG as the drying aid. The yellowness (b^*, +) of reconstituted samples was between 21.34 and 28.21, while that of the fresh juice was 20.15. All samples had significantly ($p < 0.05$) higher yellowness than the fresh juice. Considering the ΔE^* values, it was clear that the color differences between the reconstituted and fresh juices were higher using AG than MD. The color variation between the fresh and reconstituted juices is of concern if the sugarcane juice powder were to be consumed as instant beverage powder. The addition of drying adjuncts and the high drying temperature were the causes of these color deviations. Vongsawasdi et al. (2002) claimed that the lightness of the reconstituted juice was lower but the redness and the yellowness were higher than those of fresh fruit and vegetable juice due to the non-enzymatic browning (such as Maillard reaction) and caramelization occurring during the spray drying process.

The pH of reconstituted samples ranged between 5.14 and 6.04; therefore, the reconstituted juices are classified as low acid food. The pH of reconstituted samples using MD as a drying aid was significantly ($p < 0.05$) higher than the fresh juice while those of samples using AG were not significantly ($p > 0.05$) different from the fresh juice. This phenomenon requires further study for better understanding.

The percentages of insoluble solid in Table 5 illustrate that almost all of the sugarcane juice powder could be dissolved in water at room temperature. Moreover, the reconstituted samples using MD as a drying aid had lower percentages of insoluble solids than those using AG because the MD has a higher dissolution ability than AG (Cano-Chauca et al., 2005).

Drying experiment using dietary fiber as a drying aid

After drying the 30°Brix, concentrated sugarcane juice at a drying air temperature of 150 °C and applying the sugarcane fiber powder as a drying carrier at the ratio of juice to drying aid of 1:0.05, it was found that after running the dryer for a while, the feed mixture adhered to the spraying nozzle since the fiber blocked the feed flow because the fiber absorbed the water from the sugarcane juice and then expanded. Therefore, the dietary fiber from sugarcane is not an appropriate drying aid for spray drying. This result differed from the application of carrot fiber by Cheuyglintase

Table 4
Mean quality attributes (±SD) of sugarcane juice powders.

Run	Bulk density[a] (g/mL)	Moisture content[a] (% wet basis)	Water activity[a]	Solubility[a] (min)
5	0.625a ± 0.020	1.99a ± 0.02	0.241a ± 0.01	1.17a ± 0.07
6	0.571b ± 0.030	1.52b ± 0.05	0.239a ± 0.03	1.33b ± 0.04
8	0.513b ± 0.011	4.31c ± 0.09	0.198b ± 0.02	0.75c ± 0.31
9	0.555b ± 0.021	3.33d ± 0.11	0.201b ± 0.03	1.08a ± 0.34

[a] Means with the same letters within the same column are not significantly different ($p > 0.05$).

Table 5
Mean attributes (±SD) of solutions of sugarcane juice powders and fresh juice.

Run no.	Color[a,b]				pH[b]	Percentage of insoluble solid[b]
	L^*	a^*	b^*	ΔE[c]		
5	41.44a ± 1.45	−0.61a ± 0.33	21.34a ± 0.46	1.25	5.95a ± 0.05	1.75a ± 0.06
6	41.20a ± 1.59	−0.04b ± 0.27	23.39b ± 0.36	3.36	6.04a ± 0.05	1.65a ± 0.04
8	35.63b ± 1.48	1.69c ± 0.39	26.76d ± 0.37	9.36	5.15b ± 0.04	3.55b ± 0.11
9	39.85c ± 1.39	0.73d ± 0.43	28.21e ± 0.41	8.42	5.14b ± 0.02	2.70c ± 0.06
Fresh sugarcane juice (12°Brix)	41.81a ± 1.57	−0.72a ± 0.35	20.15c ± 0.44	–	5.17b ± 0.04	–

[a] L^* is lightness ($0 \le L \le 100$), a^* (+) is redness, a^* (−) is greenness, b^* (+) is yellowness and b^* (−) is blueness; values for L^*, a^*, b^*, pH and percentage of insoluble solid values are mean ± standard deviation.

[b] Means with the same letters within the same column are not significantly different ($p > 0.05$).

[c] $\sqrt{(L^*_{\text{sample}} - L^*_{\text{fresh juice}})^2 + (a^*_{\text{sample}} - a^*_{\text{fresh juice}})^2 + (b^*_{\text{sample}} - b^*_{\text{fresh juice}})^2}$.

and Morison (2009) and that of citrus fiber by Langrish and Chiou (2008) perhaps due to the dissimilar preparation method of the fiber powder and the type of fiber source between this work and these published studies.

Industrial-scale drying test

After conducting all the drying runs described in Table 3, it appeared that the drying conditions 1–3 could not produce a fine powder product. Almost all the samples were viscous and stuck inside the spray dryer. It was thought that the dissimilar conceptual design between the industrial-scale spray dryer applied in this test and the small-scale spray dryer used in the previous sections accounted for drying conditions that could produce sugarcane juice powder in the small-scale drying experiments but not in the industrial test. From Figs. 1 and 2, it is clear that the feed and drying air concurrently flow inside the drying chamber of the small-scale spray dryer whereas the feed is sprayed by the fountain nozzle in the industrial-scale dryer which causes the feed and drying air flow directions to be countercurrent during the moving up of the feed and to be concurrent during the feed falling. The use of a fountain nozzle increased the opportunity for contact between the falling dried product and the high moisture feed from the outlet of the nozzle leading to the sticky final product. A solution to this problem is to increase the ratio between the dry weight of drying aid and the weight of total soluble solid in the juice to raise the thickness of the drying aid layer that encapsulates the spray-dried juice powder. Drying runs 4–7 could produce a fine powder product since they boosted the ratio between the dry weight of drying aid and the weight of total soluble solid in juice. This ratio is equal to 1/Ratio 2 as shown in Table 3. The values of powder recovery in Table 6 indicate that by increasing this ratio from 39:61 (runs 4 and 5) to 49:51 (runs 6 and 7), the proportion of powder collected from the experiment would increase. In other words, the proportion of sample that is sticky and stuck inside the spray dryer would decrease.

Energy cost for industrial-scale production

The energy costs of the industrial-scale drying runs 4–7 are summarized in Table 6. The specific energy costs of producing sugarcane juice powder ranged between 0.77 USD and 2.06 USD per kg of powder. The specific energy costs of drying conditions 4 and 5 were remarkably high because of the very low percentage of powder recovery. Although the powder recovery from drying run 7 was the highest among these four drying runs, its specific energy cost was higher than that of run 6 because for drying run 6, the fresh juice (15°Brix) was concentrated to 30°Brix by the vacuum evaporator prior to spray drying whereas the concentration process was not applied in drying run 7. It was noted that the concentration step could evaporate the moisture from the juice with a much lower energy cost per kilogram of evaporated moisture than the spray drying process; hence, energy was saved for the powder production which applied concentration before spray-drying if the powder recovery was not considerably different. In addition, in order to reduce the specific energy cost of producing sugarcane juice powder, drying conditions that can increase the powder recovery percentage must be applied. However, the techniques to enhance powder recovery (such as increasing the proportion of drying adjunct) must be weighed against negative effects on the sensorial qualities of the product.

Conclusion

The findings in this study illustrated that sugarcane juice powder can be manufactured using the spray drying technique.

Table 6
Description of energy consumption for the industrial-scale production of sugarcane juice powder.

Run	Fresh juice weight (kg)	Energy consumption for concentration (MJ)		ECFC[a] (USD)	Energy consumption for drying (MJ)		ECFD[b] (USD)	WCP[e] (kg)	PR[f] (%)	SPEC[g] (MJ/kg of powder)	SEC[h] (USD/kg of powder)
		EE[c]	PE[d]		EE[c]	PE[d]					
4	50	46.509	120.924	1.10	93.168	242.237	2.20	1.843	14.4	197.049	1.79
5	50	44.859	116.633	1.06	110.856	288.226	2.62	1.783	14.0	227.066	2.06
6	35	42.720	111.072	1.01	89.664	233.126	2.12	4.033	37.2	85.345	0.77
7	25	–	–	–	149.664	389.126	3.53	4.456	58.6	87.326	0.79

[a] Energy cost for concentration.

[b] Energy cost for drying.

[c] Electrical energy.

[d] Primary energy = 2.6 * EE.

[e] Weight of collected powder.

[f] Powder recovery ([Dry weight of powder collected from experiment/Total solid weight in the feed mixture] * 100).

[g] Specific primary energy consumption ([PE for concentration + PE for drying]/WCP).

[h] Specific energy cost ([ECFC + ECFD]/WCP).

However, the juice must be added with a sufficient amount of drying aid such as MD and AG so that the product is in a fine powder form. Sugarcane fiber is not a suitable drying adjunct since it blocked the outlet of the spraying nozzle. The proper drying conditions were related to the conceptual design of the spray dryer. The energy cost of industrial-scale production of sugarcane juice powder ranged between 0.77 USD and 2.06 USD per kg of powder. The specific energy cost will be reduced if the sugarcane juice is concentrated by the evaporator before the spray drying process and also if the powder recovery percentage increases.

Conflict of interest statement

The authors declare that there are no conflicts of interest.

Acknowledgment

This research was financially supported by the Thailand Research Fund.

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