Physical and mechanical properties of spray dried date palm syrup powder

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ABSTRACT

The main objective of the present study was to introduce an appropriate combination of drying conditions and date palm syrup additive for producing date powder by a spray dryer. Experiments were carried out at 150, 170, and 190 °C air temperature and 380, 420 and 460 m^3/h flow rate levels. Maltodextrin at the rate of 10, 15, 20, 25, 30 and 35% of total soluble solid of syrup was used. It was found that the higher inlet temperatures resulted lower moisture contents, bulk and tapped density, cohesion, angle of repose and internal friction angle, and higher particle size, porosity, solubility and flowability.

Keywords: Date palm, Powder, Physical properties, Syrup, Spray drier

INTRODUCTION

Date palm fruit was used as a sweetener in the ancient world and still is delectable, complex fruit syrup with a variety of uses and nutritional benefits. The date syrup is an ideal substitution for sugar in favorite baking and cooking recipes. The mineral contents including potassium, magnesium and iron, make it a great alternative to sweeten up recipes without adding sugar. Fruit powders have many benefits and economic potentials over their liquid counterparts such as reduced volume or weight, reduced packaging, easier handling and transportation, and much longer shelf life.

Chopda and Barrett (2001) produced guava juice powder using freeze-drying, spray drying and tunnel drying. It was reported that the freeze-dried product had superior quality; however the spray-dried product was stable and may be more economical. Drying of fruit juice by spray dryer has been a subject of extensive research over past decades such as dried tomato pulp by spray dryer (Chopda and Barrett, 2001; Goula and Adamopoulos, 2005), watermelon powder (Quek *et al.,* 2007), pineapple powder (Weerachet *et al.,* 2009), Nopal Mucilage powder (Leon-Martinez *et al.,* 2010), dried bayberry juice (Fang and Bhandari, 2012), raspberry juice (Anekella and Orsat, 2013), and spray drying of Nopal Mucilage (Torres, 2013).

Lack of powder production due to the juice characteristics nature is main problem that has been reported in previous research. For preventing of powder stickiness two remedies were suggested, 1) using of drying agent material and 2) using of specific equipment to facilitate the powder handling (Chegini and Ghobadian, 2007). Cano-Chauca et al. (2004) studied the effect of drying agents (Maltodextrin, Arabic gum and waxy starch) on the stickiness and solubility of Mango juice dried by a spray dryer, and found that as the cellulose concentration rises in the solution, the stickiness and solubility of the final product decrease. Goula and Adamopoulos (2010) found that the combination of Maltodextrin and use of dehumidified air could effectively produce a free-flowing orange powder. Fitzpatrick et al. (2004) conducted a research on the flowability of milk powders with different fat contents, and reported that moisture sorption had only a small effect on the wall friction of each powder with small increases at higher moistures. Moreira et al. (2009) stated that higher inlet temperatures favor the desired physical properties of the powders, decrease the moisture content and hygroscopicity, and increase powder flowability. It was also found that Cashew tree gum enhanced the powder flowability.

Considering the second rank for date fruit production in Iran (Anonymous, 2013), lack of modern date fruit processing industries, and reducing the date fruit wastes the present study was conducted to produce powder from date fruit syrup and pinpoint the effects of various spray drying conditions (inlet air temperature and flow rate) on some of the physical and mechanical properties of produced powder.

MATRIALS AND METHODS

Materials

Date syrup with Brix of 78 was prepared from local market and used. The syrup was then diluted to 15 Brix with distilled water. To ensure of the absence of dispersive particles that cause congestion, each test sample was passed through a 60-mesh sieve. Then, syrup were heated up to 30 °C and some amount of Maltodextrin was gradually added to syrup for creating desired values of 10, 15, 20, 25, 30 and 35% total soluble solid for date syrup. The mixture was mixed by a laboratory blender for completely uniform syrup. The mixture then feed to dryer.

Test apparatus

A pilot-scale spray dryer consisted of a centrifugal atomizer wheel, cyclone air separator, a peristaltic pump, was used for the spray drying process. The main chamber was made of steel and had the inside diameter of 1.2 m and a total height of 2.4 m. The compressed air was dehumidified before supplying to the nozzle. Inlet drying air at different flow rates of 380, 420 and 460 m^3/h, heated up to 150, 170 and 190 ^{o}C after being passed through an electrical heater, and flowed concurrently with the spray through the main chamber. The produced powder samples were kept in airtight containers during experiments.

Powder properties

1. **Moisture content:** The moisture content was determined after that 5 g of powder was dried in an oven with 105°C temperature during 4 hrs (Chegini and Ghobadian 2007). The moisture content is expressed in terms of the percent in wet basis.
2. **Particle size distribution:** Screen analysis was done using a vibratory sieve shaker (Retsch GmbH and Co., Haan, Germany) with a series of seven sieves to determine the weighted mean diameter of particles as well as size distributions. The sieve sizes were 18, 35, 45, 70, 120, 270, 500 mesh, and a pan. A 50 g powder was fed on top sieve and operated at 60 Hz for 5 min (Niro, 1978d).
3. **Bulk and Tapped density:** two g of powder was poured to a 50 ml graduated cylinder, and then cylinder was shacked for 5 min. The bulk (ρ_{bulk}) and tapped (ρ_{tapped}) density was calculated by dividing the mass of the powder by the volume occupied in the cylinder (Niro, 1978a).
4. **Particle density:** Particle density ($\rho_{particle}$) of the powder sample was analyzed according to Niro (1978c). One g powder was poured into a 10 ml graduated cylinder with a glass stopper. Then 5 ml petroleum ether was added and shacked until all the powder particles suspended. Finally, all the powder particles on the cylinder wall were rinsed down with further 1 ml petroleum ether and the total volume of petroleum ether with suspended powder was read. The particle density was calculated as follows.

   $$\rho_{particle} = \frac{\text{weight of powder (g)}}{\text{total volume of petroleum ether with suspended powder (ml)} - 6}$$
5. **Porosity:** Porosity (ϵ) of samples was calculated by following relationship (Jinapong *et al.*, 2008):

   $$\varepsilon = \frac{(\rho_{particle} - \rho_{tapped})}{\rho_{particle}} \times 100$$
6. **Flowability and cohesiveness:** Flowability and cohesiveness of the powder were evaluated in term 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 shown below:

$\mathrm{CI} = \frac{(\rho_{tapped} - \rho_{bulk})}{\rho_{tapped}} \times 100$	$\mathrm{HR} = \frac{\rho_{tapped}\,\rho_{tapped}}{\rho_{bulk}\quad\rho_{bulk}}$

   Classification of the flowability and cohesiveness of the powders based on the CI and HR values are presented in Tables 1.
7. **Insolubility Index:** 13 g of powder was poured into a mixer jar, added in 100 ml of 24 °C distilled water and mixed for 90 seconds at 3900 rpm. Then 50 ml of sample centrifuged for 5 min at 6500 rpm, and the amount of sediment in ml was read (Niro, 1978a, 1978b).
8. **Angle of repose:** is defined as the angle between the horizontal and the slope of a heap of powder dropped from a designated elevation. About 50 g of powder poured in a funnel when bottom of funnel laid on a leveled surface. Then funnel elevated to 15 cm height. The aforementioned angle was measured using a shop protractor.
9. **Angle of internal friction:** A shear cell apparatus was made from solid plastic as shown in Fig. 1. This apparatus consisted of two cylinders with inner diameter of 3 cm and the height of 2 cm, respectively. Bottom cylinder fixed on a table and upper cylinder was movable. Both cylinders were filled with the powder and moving cylinder was connected to the universal testing machine (Santam ST-20) by a light wire cable. A cup put on the top of powder so that compressed power in cylinder. Different standard weights (100, 200, 300, 400 and 500 g) were put on the cap and the cable was pulled by Santam with a constant speed of 10 mm/min until shear force set at a nearly constant value. Relationship between the maximum values of shear

forces versus normal forces was determined by a linear regression. The values of line slope and intercept was drawn out as angle of internal friction (Φ) and cohesion (C) of the powder, respectively (Coulomb equation).

10. **Powder recovery:** Spray drying yield was determined by the ratio of the total recovered product mass to the mass of initially fed mixture into the system.

Statistical analysis

Collected data were analyzed based on factorial experiment with completely randomized design. All foregoing measurements were made in triplicate. Tukey's post-test (at p=0.05) was used to determine differences among the mean values of the physical and mechanical properties of the powder samples. The SPSS software (version 16) was used for statistical analysis.

RESULTS AND DISCUSSION

Spray drying of date syrup performed two times. At first, pure date palm syrup was used without any agent materials. Results indicated that in all of the tests no powder was produced and concentrated materials adhered to the chamber wall. Then, experiments performed with adding Maltodextrin to date syrup at sex levels of total solid of date syrup (10, 15, 20, 25, 30 and 35%). Maltodextrin yielded more powder than other agent materials. About 50% yield was obtained at 35% total soluble solid of Maltodextrin. Therefore, Maltodextrin for preparing 35% of total soluble solid of date syrup was selected for further experiments.

Results depicted that inlet air temperature and airflow rate have significant effect on powder moisture content. At constant air flow rate, increasing in inlet air temperature reduced the powder moisture content. The higher drying air temperature, the higher temperature gradient at the surface of feed drops, and therefore, it expedited the heat transfer rate and moisture evaporation from the liquid drops in the drying chamber, resulting in low moisture level of dried product. The higher drying airflow rate caused a decrease in product sojourn time in the drying chamber, and less amount of moisture removal (Fig. 2). These results are consistent with those obtained for orange powder (Chegini and Ghobadian, 2007), soymilk powder (Jinapong *et al.,* 2008), Nopal Mucilage powder (Leon-Martinez *et al.,* 2010), and orange powder (Goula and Adamopoulos, 2010).

The inlet air temperature and airflow rate have significant effect on particle size. When the drying temperature is sufficiently high, moisture is quickly evaporated and the particle skin becomes dry and hard, so that the hollow particle cannot deflate when vapor condenses within the particle as it moved into cooler regions of the dryer (Fig. 3). However, when the drying temperature is low the skin remains moist for longer time, so that the hollow particle can deflate and shrivel as it cools. According to Nijdam and Langrish (2006) milk particles dried at 200 °C were spherical and smooth, while milk particles dried at 120 °C were smaller with a shrivelled appearance. Increase in drying air flow rate results more fine particles.

Inlet air temperature and airflow rate have significant effect on bulk and tapped density (Fig. 4). As evaporation rate becomes faster, more porous or fragmented structure is obtained. According to Walton (2000) there was a greater tendency for the particles to be hollow when the drying air temperature was increased. The effect of drying air flow rate on powder bulk and tapped density depends on its effect on moisture content due to the sticky nature of the product. The higher the powder moisture content, the more particles tend to stick together, leaving more interspaces between them and consequently resulting in a larger bulk volume.

The effect of drying inlet air temperature and airflow rate on powder porosity, flowability, cohesion, angle of repose and angle of internal friction depends on moisture content and particle size of powder. Results indicated that increasing the inlet air temperature, increased porosity. As particle size increases, the spaces between the particles were also increased, lead to increased porosity.

The flowability and cohesiveness of powders varied from 20.4 to 23.3 and from 1.26 to 1.30, respectively. Based on Table 1 flowability and cohesiveness of powders were intermediate and fair, respectively. The changes in flowability and cohesiveness were significant ($p \leq 0.05$). As particle size increased, the flowability and cohesively of powder was expected to decrease (Jinapong *et al.,* 2008). However, for date palm powder the smaller particles produced larger surface area per unit mass of powder, created more cohesive forces and more frictional forces to resist against the flow (Fig. 5 and 6). Moisture content has a significant effect on the flowability and cohesiveness of powder. Liquid bridges and capillary forces acting between powder particles and reduces flowability and increases the cohesiveness of powder. In addition, moisture content plasticizes the powder material, especially the water soluble constituents, results in deformation of the powder (Kim *et al.,* 2009; Moreira *et al.,* 2009).

Solubility showed a decreasing trend with the increase in inlet air temperature (Fig. 7). This was because of the effect of inlet air temperature on particle size. Increasing the drying air temperature generally produces larger size particles and increases the dissolve time of powder. Because of rapid formation of dried layer on droplet surface, no water influenced the inner of particle when dissolved in the water (Chegini and Ghobadian, 2007). More air flow rate increases the powder moisture content and thereby decreases the powder solubility (Goula and Adamopoulos, 2005; Weerachet *et al.,* 2009).

Powder yield increased by increasing the inlet air temperature from 150 to 170 ^{0}C and the trend changed from 170 to 190 ^{0}C. The higher drying air temperatures from 150 up to 170 ^{0}C, the faster drying times and the higher powder gained. However, heating up the air more than 170 ^{0}C caused to melt of the produced powder and cemented them on the dryer wall. Increasing in air flow rate from 380 to 420 m^3/hr reduced the drying time and lead more powder yield. Whilst, increasing air flow rate from 420 to 460 removed tiny particles from the drying chamber, and resulted yield reduction.

As shows in Fig. 8 there is a linear relationship between internal friction angle (Φ) and particle size (ps). The trend of calculated cohesion (CI) and measured one (C) versus particle size followed same direction, but higher correlation was obtained between measured cohesion and particle size (Fig. 9).

Using Graph Pad 6.01 computer program the slope and intercept of CI versus C curve was compared with y=x line. No significant difference was observed between the slopes, but significant intercept implied that cohesion is overestimated by formula (C) by an error about 2.7 percent.

CONCLUSION

The results of the present study revealed that drying of date syrup without agent drying materials do not produce powder even with alteration in dryer operating parameters such as inlet air temperature and flow rate. The Maltodextrin was a suitable drying material agent to increase the dryer yield. The results of statistical analysis showed that the inlet air temperature and flow rate significantly influenced on physical and mechanical properties of date palm powder.

Literature Cited

Anonymous, 2013. FAOSTAT. http://faostat3.fao.org/home/index.html#COMPARE. (Visited on June 2013)

Anekella, K. and Orsat, V. 2013. Optimization of microencapsulation of probiotics in raspberry juice by spray drying. Food Science and Technology. 50: 17-24.

Cano-Chauca, M., Stringheta, P. C., Sardagna, L. D. and Cal-Vida, J. 2004. Mango juice dehydration sprays drying using different carriers and functional characterization. Paper presented at the 14th International Drying Symposium.

Carr, R. L. 1965. Evaluating flow properties of solids. Chemical Engineering, 72, 163-168.

Chegini, G. R. and Ghobadian, B. 2007. Effect of spray-drying condition on physical properties of orange juice powder. Drying Technology. 23: 657-668.

Chopda, C. A. and Barrett, D. M. 2001. Optimization of Guava juice and powder production. Journal of Food Processing. 25: 411-430.

Fang, Z. and Bhandari, B. 2012. Comparing the efficiency of protein and maltodextrin on spray drying of bayberry juice. Food Research International. 48: 478-483.

Fitzpatrick, J. J., Iqbal, T., Delaney, C., Twomey, T. and Keogh, M. K. 2004. Effect of powder properties and storage condition on the flowability of milk powders with different fat contents. Journal of Food Engineering. 64: 435-444.

Goula, A. M. and Adamopoulos, K. G. 2005. Spray drying of tomato pulp in dehumidified air: II. The effect on powder properties. Journal of Food Engineering. 66: 25-42.

Goula, A. M. and Adamopoulos, K. G. 2010. A new technique for spray drying orange juice concentrate. Innonative Food Science and Emerging Technologies. 11: 342-351.

Hausner, H. H. 1967. Friction conditions in a mass of metal powder. International Journal of Powder Metallurgy. 3: 7-13.

Jinapong, N., Suphantharika, M. and Jamnong, P. 2008. Production of instant soymilk powders by ultrafiltration, spray drying and fluidized bed agglomeration. Journal of Food Engineering. 87: 194-205.

Kim, E. H. J., Chen, X. D. and Pearce, D. 2009. composition of industrial spary dried milk powder . 2: Effect of spary drying conditions on the surface composition. Journal of Food Engineering. 94: 169-181.

Leon-Martinez, F. M., Mendez-Lagunas, L. L. and Rodriguez-Ramirez, J. 2010. Spray drying of nopal mucilage (Opuntia ficus-indica): Effects on powder properties and characterization. Journal of Carbohydrate Polymers. 81: 864-870.

Moreira, G. E. G., Costa, M. G. M., Souza, A. C. R., Brito, E. S., Medeiros, M. F. D. and Azeredo, H. M. C. 2009. Physical properties of spray dried acerola pomace extract as affected by temperature and drying aids. Food Science and Technology. 42: 641-645.

Nijdam, J. J. and Langrish, T. A. G. 2006. The effect of composition on the functional properties of milk powders. Journal of Food Engineering. 77: 919-925.

Niro, A. S. 1978a. Determination of Bulk density. In I. H. Sorensen, J. Karg, J. Pisecky & V. Westergaad (Eds.), Analytical methods for dry milk products (pp. 18–19). Copenhagen, Denmark: De Forenede Trykkerier A/S.

Niro, A. S. 1978b. Determination of Solubility index. In I. H. Sorensen, J. Karg, J. Pisecky & V. Westergaad (Eds.), Analytical methods for dry milk products (pp. 52-53). Copenhagen, Denmark: De Forenede Trykkerier A/S.

Niro, A. S. 1978c. Determination of particle density, content of occluded air and interstitial air. In I. H. Sorensen, J. Karg, J. Pisecky & V. Westergaad (Eds.), Analytical methods for dry milk products (pp. 52-53). Copenhagen, Denmark: De Forenede Trykkerier A/S.

Niro, A. S. 1978d. Determination of Particle size distribution by sieving. In I. H. Sorensen, J. Karg, J. Pisecky & V. westergaad (Eds.), Analytical methods for dry milk products (pp. 52-53). Copenhagen, Denmark: De Forenede Trykkerier A/S.

Quek, S. Y., Chok, N. K. and Swedlund, P. 2007. The physicochemical properties of spary dried watermelon powders. Chemical Engineering and Processing. 46: 389-392.

Torres. (2013).

Walton, D. E. (2000). The morphology of spray-dried particles: A qualitative view. Drying Technology. 18: 1943-1986.

Weerachet, J., Siriwan, N. A. and Onuma, T. 2009. Study of Spray Drying of Pineapple Juice Using Malt dextrin as an Adjunct. Food Science and Technology. 37: 498-506.

Table

Table 1. Classification of powder flowability and cohesiveness

CI (%)	Flowability	HR	Cohesiveness
<15	Very good	<1.2	Low
15–20	Good	1.2–1.4	Intermediate
20–35	Fair	>1.4	High
35–45	Bad		
>45	Very bad		

Figures

Fig. 1. Apparatus for determining the shear strength of powder

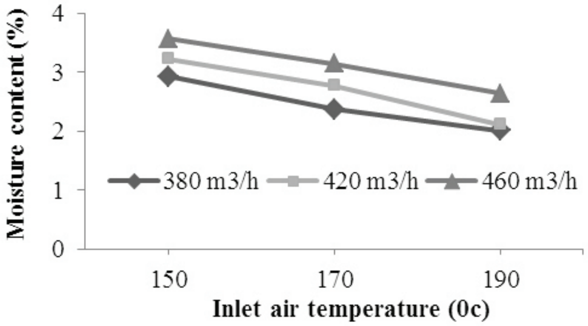

Fig. 2. The effect of inlet air temperature and air flow rate on moisture content

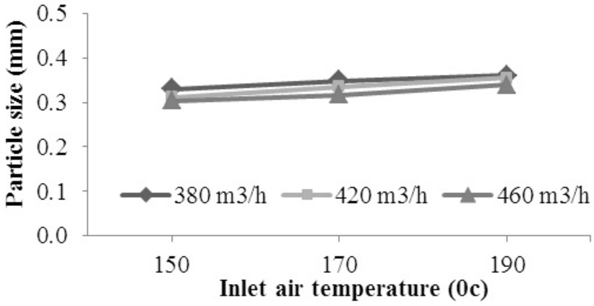

Fig. 3. The effect of inlet air temperature and air flow rate on particle size

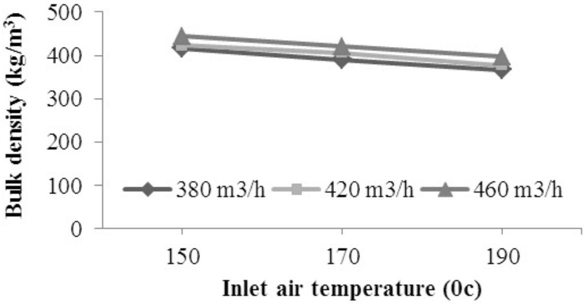

Fig. 4. The effect of inlet air temperature and air flow rate on bulk density

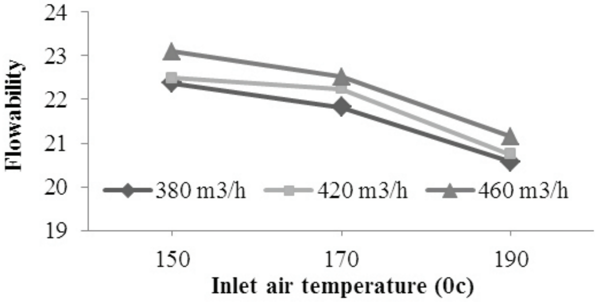

Fig. 5. The effect of inlet air temperature and air flow rate on flowability

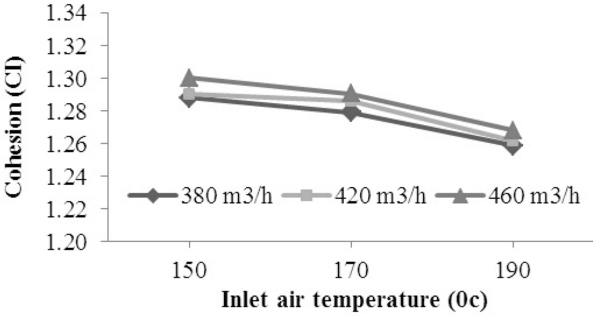

Fig. 6. The effect of inlet air temperature and air flow rate on cohesion

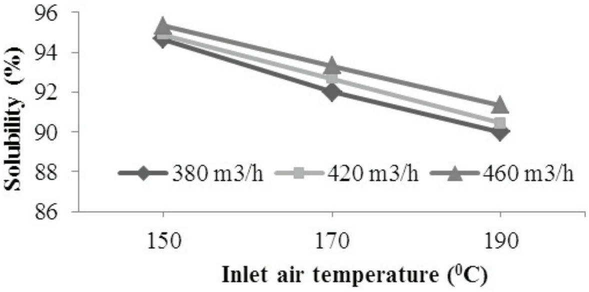

Fig. 7. The effect of inlet air temperature and air flow rate on solubility

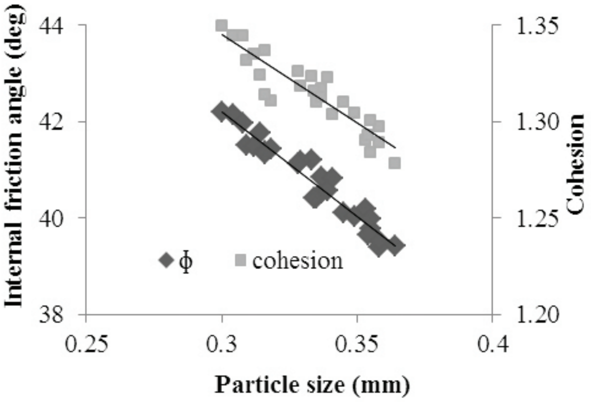

Fig. 8. Relationship between internal friction angle (Φ) and cohesion based on the particle size

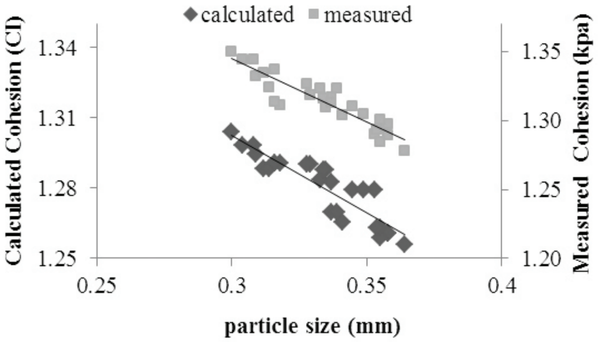

Fig. 9. Calculated and measured cohesion versus particle size