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A new technique for spray drying orange juice concentrate

Athanasia M. Goula [a,b,*], Konstantinos G. Adamopoulos [b]

[a] Department of Food Science and Technology, Faculty of Agriculture, Aristotle University, 541 24 Thessaloniki, Greece
[b] Division of Chemical Engineering, School of Engineering, Aristotle University, 541 24 Thessaloniki, Greece

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ABSTRACT

A new technique for spray drying concentrated orange juice using dehumidified air as drying medium and maltodextrin as drying agent was developed. A pilot-scale spray dryer was employed for the spray drying process. The modification made to the original design consisted in connecting the dryer inlet air intake to an absorption air dryer. 21 DE, 12 DE, and 6 DE maltodextrins were used as drying agents. Concentrated orange juice was spray dried at inlet air temperatures of 110, 120, 130, and 140 °C and (concentrated orange juice solids)/(maltodextrin solids) ratios of 4, 2, 1, and 0.25. Data for the residue remaining on the walls were gathered and the powders were analyzed for moisture content, bulk density, rehydration, hygroscopicity, and degree of caking. The combination of maltodextrin addition and use of dehumidified air was proved to be an effective way of reducing residue formation.

Industrial relevance: Orange juice powder has many benefits and economic potentials over its liquid counterparts and provides a stable, natural, easily dosable ingredient, which generally finds usage in many foods and pharmaceutical products such as flavoring and coloring agents. However, the dehydration of orange juice is not a simple task. Thus, the objective of this study was to develop a new technique for spray drying orange juice using dehumidified air as drying medium and maltodextrin as drying agent.

1. Introduction

Spray drying is the transformation of feed from a liquid or slurry form to a dry powder. The feed is atomized into a chamber where the resulting spray mixes with hot gas, which evaporates the liquid component of the spray leaving dried particles. One of the main indices of a spray dryer performance is product recovery. Material loss in a spray drying system is due mostly to the adhesion of droplets to the wall of the apparatus (Maa, Nguyen, Sit, & Hsu, 1998; Masters, 1979). Retention of product on the chamber wall over lengthy time is undesirable. It affects product quality, as deposits can become scorched and when dislodged, mix in and contaminate the entire product. Furthermore, it is not cost-effective due to a more frequent shut down of the dryer for cleaning.

The products to be spray dried can be categorized into two major groups: non-sticky and sticky products. Sticky products are generally difficult to spray dry. During the drying process they may remain as syrup or stick on the dryer wall, or form unwanted agglomerates in the dryer chamber and conveying system (Bhandari & Howes, 2005; Hennings, Kockel, & Langrish, 2001). The problem of powder stickiness is mainly due to the low glass transition temperature (*Tg*) of the low molecular weight sugars present in such products, essentially sucrose, glucose, and fructose (Bhandari, Senoussi, Dumoulin, & Lebert, 1993; Roos, Karel, & Kokini, 1996).

Fruit juice 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. Besides, their physical state provides a stable, natural, and easily dosable ingredient, which generally finds usage in many foods and pharmaceutical products such as flavoring and coloring agents (Shrestha, Ua-arak, Adhikari, Howes, & Bhandari, 2007). However, the dehydration of fruit juices is not a simple task. The low *Tg* of the main juice components (low molecular weight sugars and organic acids) as well as their high hygroscopicity, low melting point, and high water solubility result in highly sticky product when spray dried.

Various methods capable of producing a free-flowing fruit juice powder have been proposed: addition of drying aids (maltodextrins, glucose, soybean protein, sodium chloride, and skim milk powder) (Adhikari, Howes, Bhandari, & Truong, 2003, 2004; Bhandari et al., 1993; Bhandari, Datta, Crooks, Howes, & Rigby, 1997; Brennan, Herrera, & Jowitt, 1971; Chegini & Ghobadian, 2005; Chegini, Khazaei, Ghobadian, & Goudarzi, 2008; Jaya & Das, 2004; Lazar, Brown, Smith, Wong, & Lindquist, 1956; Papadakis, Gardeli, & Tzia, 2006; Quek, Chok, & Swedlund, 2007; Rao & Gupta, 2002; Roustapour, Hosseinalipour, & Ghobadian, 2006; Shrestha et al., 2007; Tsourouflis, Flink, & Karel, 1976), scrapping of dryer surfaces (Karatas & Esin, 1994),

* Corresponding author. Department of Food Science and Technology, Faculty of Agriculture, Aristotle University, 541 24 Thessaloniki, Greece. Tel.: +30 2310 995903; fax: +30 2310 996259.
E-mail addresses: athgoula@gmail.com, athgou@agro.auth.gr (A.M. Goula).

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cooling of the drying chamber walls (Chegini & Ghobadian, 2005; Chegini et al., 2008; Gransmith, 1971; Jayaraman & Das Gupta, 1995; Spicer, 1974), and admission of atmospheric air near the chamber bottom, allowing transport of the powder to a collector having a low humidity atmosphere (Ponting, Stanley, & Copley, 1973).

The major components of orange juice such as fructose, glucose, and citric acid have very low *Tg* of 5, 31, and 16 °C, respectively, in a pure, dry state, which decrease drastically when moisture is absorbed. Due to this characteristic, the spray drying of orange juice is complex. Shrestha et al. (2007) produced orange juice powder by spray drying a mixture of juice and maltodextrin with DE of 6 at 160 °C. Tsourouflis et al. (1976) mentioned that when used as drying aids for orange juice, low-dextrose equivalent maltodextrins were found to give higher collapse temperatures than high-DE maltodextrins at the same concentrations. Chegini and Ghobadian (2005) carried out spray drying of orange juice using additives (maltodextrin, glucose, and methylcellulose) at high concentrations and a modified dryer with a jacketed wall for air-cooling.

The major limitations of the use of drying aids are the subsequent change in the product properties and the cost. As far as the cooling of the drying chamber walls is concerned, the cool wall will be favorable to minimize the thermoplastic particles from sticking, as the wall will be cold enough to cool and solidify the outer surface of the thermoplastic particles coming in contact. This method, however, was found to improve the process but not to resolve the problem. The reason is that the cold chamber wall will also cool the surrounding environment and cause an increase in the relative humidity of the air close to the wall surface.

Considering the difficulty in obtaining orange juice powder, the objective of this study was to develop a new technique for spray drying orange juice concentrate using dehumidified air as drying medium and maltodextrin as drying agent.

2. Materials and methods

2.1. Raw materials

Concentrated orange juice with a total solids mass concentration of 62.0 ± 0.3%, containing 43.1 ± 0.5 g/100 mL sugars and 4.3 ± 0.1 g/100 mL citric acid, obtained from a local manufacturer, was used. 21 DE, 12 DE, and 6 DE maltodextrins (Glucidex®, Roquette, France) were used as drying agents. Taking into account the moisture content of orange juice concentrate and of maltodextrin powders (2.5, 3.5, and 4.5%, respectively), solutions with the desired total solids concentration and the desired ratio of (concentrated orange juice solids)/(maltodextrin solids) were prepared. These solutions were subsequently used as feeds to the spray dryer.

2.2. Spray drying

A pilot-scale spray dryer (Buchi, B-191, Buchi Laboratoriums-Technik, Flawil, Switzerland) with cocurrent regime and a two-fluid nozzle atomizer was used for the spray drying process. The atomizer had an inside diameter of 0.5 mm and used compressed air with a flow rate that was controlled by a variable area flow meter. Feed was metered into the dryer by means of a peristaltic pump. Inlet drying air, after passing through an electrical heater, flowed concurrently with the spray through the main chamber. The main chamber was made of thick transparent glass and had an inside diameter of 10.5 cm and a total height of 52.5 cm. The distance between the tip of the atomizer and the axis of the side exit tube was 34.9 cm. The bottom of the chamber is cone shaped and makes an angle of 60° with the walls. A cyclone air separator/powder recovery system was used. Dried powder samples were collected from the base of the cyclone. The design of the dryer is such that the outlet air temperature, contrary to the inlet temperature, cannot be set with a temperature regulator, but results from a combination of the inlet temperature, the aspirator setting, the pump setting, as well as the concentration of the feed. The modification made on the original design consisted of connection of the spray dryer inlet air intake nipple with an air drying unit by a flexible plastic air duct. The compressed air was also dehumidified before its supply to the two-fluid nozzle. An Ultrapac 2000 adsorption dryer (Model 0005, Ultrafilter International AG, Haan, Germany) with two desiccant cartridges was used to dry air down to 0.01 g of water per kg of dry air.

Forty-eight different experiments were conducted in triplicate. The controlled parameters were the DE of the maltodextrin (*DE*), the ratio (concentrated orange juice solids)/(maltodextrin solids) (*o*:*m*), and the inlet air temperature (*Ti*). 21 DE, 12 DE, and 6 DE maltodextrins were used as drying agents. Orange juice concentrate was spray dried at inlet air temperatures of 110, 120, 130, and 140 °C (±1°C) and (concentrated orange juice solids)/(maltodextrin solids) ratios of 4, 2, 1, and 0.25. In all experiments the atomizer pressure, the feed rate, the feed solids concentration, and the feed temperature were kept at 5.0 ± 0.1 bar, 1.8 ± 0.1 g/min, 35.0 ± 0.2%, and 32.0 ± 0.5 °C, respectively. Moreover, in a previous work, it was found that the lowest wall deposition rate was achieved at a drying air flow rate of 22.8 ± 0.2 m^3/h and a compressed air flow rate of 800 ± 20 L/h (Goula & Adamopoulos, 2005a). These conditions were used for all the experiments reported here.

2.3. Spray dryer performance

The weights of the drying chamber and the receiving vessel for powder were determined before and after spray drying by an electronic balance with an accuracy of 10^{-2} g. Residue yield (n_r) was determined by dividing the weight of solid mass collected in the chamber with the total amount of solid mass to be spray dried.

2.4. Glass transition temperature measurement

Samples of orange juice powder of about 1 g (±0.01 g), produced by spray drying of orange juice concentrate at 140 °C without maltodextrin, were conditioned at 25 °C using sulphuric acid solutions to maintain the water activity at ten levels between 0.04 and 0.95, according to sorption isotherm methodology (Al-Muhtaseb, McMinn, & Magee, 2004). After equilibrium was reached, samples of about 10 mg were taken for differential scanning calorimetry (DSC) analysis and the remaining material was analyzed for moisture content by drying in a vacuum oven at 70 °C until consecutive weighings, made at 2 h intervals, gave less than 0.3% variation. The glass transition temperature was determined by DSC, with a differential scanning calorimeter (Perkin-Elmer Pyris 1, PerkinElmer Life and Analytical Sciences Inc., Wellesley, MA) supplied with proper software. The rate of thermal scanning was carried out in the following order: 1) isothermal at −80 °C for 1 min; 2) heating at 10 °C/min from −80 °C to a temperature just over the predetermined apparent *Tg*; 3) cooling at 50 °C/min to −80 °C; 4) heating at 10 °C/min from −80 to 60 °C. The midpoint of the glass transition was considered as the characteristic temperature of the transition. All measurements were done in triplicate.

The glass transition temperature of a binary solid–water mixture is strongly dependent on the water concentration. Once the moisture content is known, the *Tg* can be determined using the model proposed by Gordon and Taylor (Ozmen & Langrish, 2002):

$$Tg = \frac{(1-x_w)\cdot Tg_s + k\cdot x_w \cdot Tg_w}{(1-x_w) + k\cdot x_w} \quad (1)$$

where *Tg*, Tg_s, and Tg_w are the glass transition temperatures of the mixture, solids, and water, respectively, x_w is the mass fraction of water, and *k* is the Gordon-Taylor parameter.