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Effect of process variables on the drying of guava pulp by cast-tape drying

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ABSTRACT

Cast-tape drying (CTD) is a relatively new technique for dehydration and production of food powders. A solution or suspension is spread over a flexible support heated by water or steam. This study investigated the effect of flexible support type (polyester film – Mylar® or fiberglass coated with Teflon®) and pulp layer thickness (2 mm and 3 mm) on drying rate and temperature of guava pulp processed by CTD. All drying curves presented constant-rate period, which was 2.1 greater using 2 mm thick-pulp than 3 mm thick-pulp, for both Mylar® and Teflon®. Using same pulp thickness, similar drying rates and evaporative capacities were observed for both flexible supports. Guava pulp was less sticky on Teflon® than on Mylar® support and that is an advantage. Therefore, cast-tape drying can be used for production of guava powder with high drying rates and evaporative capacities.

1. Introduction

Guava (*Psidium guajava* L.) is native of America's tropical regions and can be processed to produce juice, pulp and nectar (Brunini, Oliveira, & Varanda, 2003). Guava is known as a "super fruit", for its nutritional importance in terms of vitamins A and C and seeds rich in omega 3, omega 6, polyunsaturated acids, riboflavin, protein and minerals (Kadam, Kaushik, & Kumar, 2012). Guava fruit also contains polyphenols and carotenoids, which belong to major classes of antioxidants pigments. Red guavas have a higher value as sources of antioxidants than white guavas (Nimisha, Kherwar, Ajay, Singh, & Usha, 2013).

As raw guavas have limited shelf life, the development of methods for their preservation and processing is important to avoid losses and to add value to resulting products. Dehydration is a suitable technique to achieve this objective (Verma, Singh, Kaur, Mishra, & Rai, 2015). In addition, powder production is an alternative to extending shelf life of some foodstuffs, leading to a product with good commercial value and easier handling, packaging, and transportation (Cuq, Rondet, & Abecassis, 2011).

Cast-tape drying (CTD) is a dehydration process applicable to viscous suspensions or solutions, with intend to concentrate the pulp, or dry it to produce films, flakes and powders (Durigon, Parisotto, Carciofi, & Laurindo, 2017; Durigon, de Souza, Carciofi, & Laurindo, 2016). In this process, food suspension (e.g., fruit pulp) is spread on the upper face of a flexible support (polyester film – Mylar® - or fiberglass coated with Teflon®), which is heated by a hot fluid on its bottom face (Nindo & Tang, 2007). Usually, the bottom face of support is heated by hot water, but a recent study reported use of water vapor as suitable heating media (Durigon et al., 2017). Thus, during drying, energy for evaporation can be supplied by heat conduction (through support and the fruit pulp) and convection (from flowing air over pulp). Thermal radiation emitted by the heating media (hot water or water vapor) can be neglected, even if the flexible support is transparent to thermal radiation, as reported by literature (Durigon et al., 2017, 2016; Ortiz-Jerez & Ochoa-Martínez, 2015; Ortiz-Jerez, Gulati, Datta, & Ochoa-Martínez, 2015; Zotarelli, Carciofi, & Laurindo, 2015). Therefore, CTD is an alternative for drying heat-sensitive foods as fruits, vegetables and herbs. As drying temperatures are moderate (in range of 70–75 °C) and drying times are not very prolonged, quality parameters like color, retention of vitamins and antioxidants are frequently reported (Abonyi et al., 2002; Caparino et al., 2012; Castoldi, Zotarelli, Durigon, Carciofi, & Laurindo, 2015; Durigon et al., 2017, 2016; Nindo & Tang, 2007; Nindo, Feng, Shen, Tang, & Kang, 2003; Pavan, Schmidt, & Feng, 2012; Zotarelli et al., 2015).

Abonyi, Tang, and Edwards (1999) concluded that CTD has unique potential for dehydration of fruits with high sugar content, even without addition of carrier agents. Besides, retention of heat-sensitive nutrients is very impressive and is close to the observed on freeze dried products. Additionally, CTD process has advantages of providing high drying rates, high energy efficiency and low costs (Abonyi et al., 2002; Durigon et al., 2017, 2016; Nindo, Powers, & Tang, 2007; Zotarelli, da Silva, Durigon, Hubinger, & Laurindo, 2017).

Zotarelli et al. (2015) reported the use of CTD for drying of mango

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pulp, using water at 95 °C as the heating media and pulp with 2 mm thickness. On these processing conditions, they reported drying rate of 0.6 g/(g.min) resulting in an evaporative capacity up to 10 kg/(m^2.h), indicating a very efficient drying process. Durigon et al. (2017) reported experimental results on the CTD drying of tomato pulp, and observed that CTD process provides high drying rates and evaporative capacities of 15–17 kg/(m^2.h), using Mylar® and Teflon® as flexible supports.

Studies reporting guava drying by CTD or similar drying processes were not found in literature. This study aimed to investigate the influence of pulp thickness and support type (polyester film - Mylar® - and fiberglass coated with Teflon®) on drying rates of guava pulp dried by CTD.

2. Material and methods

2.1. Guava pulp

Commercial guava pulp was purchased from local market (Florianópolis, SC, Brazil - 27°35′48″ S, 48°32′57″ W). The pulp was triturated in a blender (Arno, São Paulo, SP, Brazil) at minimum power for 1 min, and sifted in a 16-mesh sieve. Samples presented soluble solids between 5.0 and 6.6 °Brix, determined with a manual refractometer (ATAGO, model PAL-BX/RI, Tokyo, Japan). The water activity (a_w) of guava pulp was 0.995 ± 0.001, while for guava powders the average a_w was 0.268 ± 0.039. The moisture content, in dry basis, ranged from 8.19 to 10.36 g/g, determined by gravimetric method (AOAC, 2012) using a vacuum oven at 70 °C (TECNAL, model TE-395, Brazil).

2.2. Experimental device

The CTD device, which uses steam as heating media at bottom surface of the flexible support, is schematically represented in Fig. 1.a. It consists of a reservoir made of stainless steel (0.80 m × 0.40 m x 0.20 m), partially filled with water. A pump (KOMECO, model TP 40 G3, Palhoça, SC, Brazil) was used for stirring the water into the reservoir in a closed circuit. Two electrical resistors promoted water heating (98 ± 1 °C) to produce vapor that filled the space between water surface and bottom surface of the flexible film. Water temperature, into the reservoir, was measured by PT100 sensors (Alutal® Controles Industrial, model TRS12, Votorantim, SP, Brazil). Airflow above the support and fruit pulp was promoted by a fan and an exhauster (Qualitas Indústria Eletromecânica Ltda, model FAQ8, Itapira, SP, Brazil). The volumetric flow rate of inlet/exhaustion air was 198.07 ± 51.65 m^3/h.

A flexible film (0.25 mm thick) was used as the support on which the guava pulp was spread. A fiberglass fabric with 59% of polytetrafluoroethylene -Teflon® (Indaco, Sheet Armalon® Standard, São Paulo, Brazil) and a polyester film (Mylar® type D, DuPont, Wilmington, DE, USA) were tested as flexible support.

2.3. Experimental procedure

The water contained in CTD equipment was pre-heated until 98 °C before spreading guava pulp on flexible supports (fiberglass-Teflon® fabric or polyester film - Mylar®). Spreading of pulp with 2 mm or 3 mm thickness was executed with a doctor-blade (Tape Casting Warehouse, model Doctor Blade Assembly, Morrisville, PA, USA).

Drying experiments were performed in triplicate with inlet air temperature (21.0 ± 5.0 °C) and relative humidity (65–75%) measured by thermo-hygrometer (Testo, model 610, Lenzkirch, Baden-Württemberg, German). Air velocities above the pulp during drying were measured by thermo-anemometer (Testo, model 425, Lenzkirch, German) placed 2 cm above the support at four different positions (V1, V2, V3 and V4, as shown in Fig. 1.b). Guava pulp was removed from three different regions of the flexible support to have an average behavior of the drying curve. Pulp moisture was determined at each 2 min to have enough information on the drying kinetics during the whole process (Castoldi et al., 2015; Durigon et al., 2016; Zotarelli et al., 2015, 2017). These samples moistures were determined by gravimetric method under vacuum, at 70 °C (TECNAL, model TE-395, Piracicaba, SP, Brazil), according to AOAC (2012).

2.3.1. Temperature measurements

The temperature of pulp (positions T1, T2, T3, T4, T5 and T6 in Fig. 1.b), air (positions T7, T8, T9, T10, T11 and T12 in Fig. 1.b) and vapor touching the support bottom (positions T13, T14, T15 e T16 in Fig. 1.b) during drying, were measured at each interval of 30 s with T-type thermocouples (IOPE, A-TX-TF-R-30AWG, São Paulo, SP, Brazil) coupled to a data acquisition system (Agilent, 34970A, Bayan Lepas, Penang, Malaysia). Guava pulp temperature was also measured using a thermographic camera (Flir, model T360, Täby, Sweden), placed at approximately 1.5 m above the pulp. Thermographic images were captured soon after spreading and then every 2 min, being after analyzed using specific software (FLIR QuickReport 1.2 SP2, Täby, Sweden).

2.4. Drying rate and evaporative capacity

The constant drying rate (dX/dt) during drying of guava pulp by CTD was determined by the slope of linear equation fitted to the linear part of each drying curve. The evaporative capacity (water evaporation rate per unit area, E), was calculated according to Equation (1):

$$E = -dX/dt(1 - U_m)\rho L \tag{1}$$

where U_m is initial moisture content in wet basis, determined as average value of triplicates (0.899 ± 0.008 kg/kg), ρ is initial guava pulp density (1.02 ± 0.002 kg/m^3) measured by a pycnometer, and L is the pulp layer thickness (2 mm or 3 mm).

2.5. Statistical analysis

A multiple comparison of average values, considering natural raw material variability, was performed with One-way ANOVA and Tukey's test at 90% confidence level ($p < 0.10$), using software Statistica 8.0 (Statsoft Inc., Tulsa, OK, USA).

3. Results and discussion

3.1. Drying kinetics and evaporative capacity of CTD

Fig. 2 shows guava pulp drying curves (triplicates), for pulps with thicknesses of 2 mm and 3 mm, using Teflon® and Mylar® as support. All drying curves exhibited a constant-rate period assured by coefficients of determination r^2 higher than 0.99. The duration of this drying period for both supports was 6 min for 2 mm-thick pulp (Fig. 2.a, Fig. 2.c), and 14 min for pulp thickness of 3 mm (Fig. 2.b, Fig. 2.d).

The drying time to reach pulp moisture of approximately 0.02 g/g (final moisture content) was determined through the drying curves, being 10 min for 2 mm-thick guava pulp and 18 min for 3 mm-thick pulp, in both flexible supports (Mylar® and Teflon®). From similar drying conditions, Durigon et al. (2017) reported that the drying time of tomato pulp was reduced from 12 min to 10 min when air velocity was increased from 0.34 ± 0.04 to 1.35 ± 0.11 m/s.

Drying rates during the constant-rate period, obtained from linear equations fitted to part of the experimental curves, and the evaporative capacities calculated from Equation (1), are presented in Table 1 and Table 2, respectively. Several authors observed constant-rate periods during drying of fruit pulps by CTD with 2 and 3 mm thickness (Castoldi et al., 2015; Durigon et al., 2017; Zotarelli et al., 2015). The constant drying rate period observed during cast-tape drying is explained by