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Dehydration of acerola (*Malpighia emarginata* D.C.) residue in a new designed rotary dryer: Effect of process variables on main bioactive compounds

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ABSTRACT

Residues of acerola generated as byproduct of fruit processing industry have been studied in this work, due to its potential use as food supplementation. To ensure proper processing, a detailed characterization of the acerola residues has been performed. The dehydration of these residues in a new dryer, named as roto-aerated dryer, has been investigated in this work. The effect of a pre-treatment with ethanol prior to the air-drying has also been analyzed. The performance of this new dryer and the effect of processing variables have been investigated considering the drying responses, as well as the quality of product. The product quality has been quantified considering the content of bioactive compounds (total phenolic content, citric acid content and total flavonoid compound). The results shown that the new dryer proved to be a good alternative for drying of acerola residue, due to the high drying rate and the good quality of the product after drying..

1. Introduction

Acerola (*Malpighia emarginata* D.C.) is a tropical fruit originates from tropical America. Its pleasant flavor and the high levels of vitamin C have led to its increasing use in the form of juice, jelly and compote. The byproducts of fruit processing industry, such as seeds, kernels and bagasse, which were previously considered wastes, have high potential use as food supplementation (Ribeiro et al., 2005), because these residues can contain higher amounts of phenolic and other bioactive compounds than the edible fleshy parts (Bortolotti et al., 2013). It is estimated that 40% of the volume of processed fruits are residues that are not used (Duzzioni et al., 2013). These aspects, along with the increasing global interest in environmental friendly technologies, explain the recent interest in the utilization of byproducts of fruit processing industry (Silva et al., 2011). However, to ensure an adequate use of these materials is of fundamental importance to accurately characterize their properties, especially physical and chemical characteristics (Barrozo et al., 2004).

Fruit residues may contain more than 80% of water, which limits their shelf life and complicates their transport and storage. Thus, to reduce the moisture content, it is necessary to submit these residues to a dehydration process. Drying of food can be performed in several devices (Barrozo et al., 2001; Kaya et al., 2010). Rotary dryers (Nonhebel and Moss, 1971) are interesting alternative for dehydration of the fruit residues, because of their flexibility in handling a wider range of materials than other types of dryers (Arruda et al., 2009a; Lobato et al., 2008) and their high processing capacity (Fernandes et al., 2009).

The conventional configuration of rotary dryer consists of a horizontally inclined drum, able to rotate on its own axis, being internally equipped with flights. Solids are transported

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Nomenclature

A	area of the ellipse with the same area of the particle projection (mm^2)
AC_{50}	mean sieve opening (mm)
AF_{50}	mean length of particles (mm)
AM_{50}	mean width of particles (mm)
AR_{50}	mean aspect ratio of particles (dimensionless)
k_f	specific tolerance factor
$M_{Removed}$	moisture removed (%)
Rd_{50}	mean roundness of particles (dimensionless)
R_w	drying rate ($g\,min^{-1}$)
SD	standard deviation
TA	total titrable acidity (mg citric acid $100\,g^{-1}$ samples (dry matter))
TFC	total flavonoid content (μgrutin100 g^{-1} samples (dry matter))
TPC	total phenolic content (mg gallic acid $100\,g^{-1}$ samples (dry matter))
T_{Solid}	solid temperature (°C)
x_c	sieve opening related to particle size (mm)
$x_{c\text{-}min}$	minimum sieve opening related to particle size (mm)
$x_{Fe\text{-}max}$	maximum Feret diameter (mm)
$x_{Fe\text{-}min}$	minimum Feret diameter (mm)
x_{Ma}	maximum Martin diameter (mm)
$x_{Martin\text{-}min}$	minimum Martin diameter (mm)

through the drum by cascading from the flights, each cascade comprising the cycle of lifting on a flight and falling through the air stream (Silverio et al., 2011). Most of the drying occurs during the free fall of solids from the flights, when the solids are in close contact with the hot air. Drying process using the conventional rotary dryer is energy intensive and consequently cost intensive.

Considering the significant operational cost, several studies have focused on design modifications of rotary dryers to improve their performance. Thus, another version of the rotary dryer, named as roto-aerated dryer, was designed by our research group. The main characteristic of this non-conventional rotary dryer was the effective contact time between hot air and wet solids and consequently the drying efficacy (Arruda et al., 2009b; Silverio et al., 2015). The main feature of this new dryer is the presence of an aerated system (Lisboa et al., 2007) consisting of a central pipe (surrounded by the drum) from which a series of mini-pipes conduct the hot air directly to the particle bed flowing at the bottom. The roto-aerated dryer does not contain any flights. A dryer similar to the roto-aerated, named as rotary dryer Yamato, is presented in Kudra and Mujumdar (2009). The main differences between these non-conventional rotary dryers are the arrangement and distribution of the mini-pipes and the relative position between the mini-pipes and particles bed. Fig. 1 shows the inside view of the conventional rotary dryer (a) and roto-aerated dryer (b).

In the roto-aerated dryer, the gas-particle contact occurs as long as the solid remains in the dryer, differently from the cascading conventional dryer where this contact occurs mostly during the time that the particles are falling from the flights (Arruda et al., 2009a).

In all previous works performed with the roto-aerated dryer, this new dryer was used for fertlizer drying. Arruda et al. (2009a) compared the performance of a conventional rotary dryer with a roto-aerated dryer at same operating conditions. These authors observed that the residence times for the roto-aerated dryers were 48% smaller (on average) than for the conventional cascading rotary. Arruda et al. (2009b) proposed a modeling approach to study the heat and mass transfer between the air and the particles of super-phosphate fertilizer in conventional rotary and roto-aerated dryers. In these two works (Arruda et al., 2009a,b), the roto-aerated dryer had 56 mini-pipes of 9 mm diameter. Later, Silverio et al. (2015) designed a new roto-aerated dryer configuration, named as hybrid roto-aerated dryer, having two different mini-pipes diameters (0.009 m and 0.006 m, in an interleaved arrangement). The performance of this hybrid roto-aerated dryer was compared with conventional cascade dryers for fertilizer drying. The difference between inlet and outlet solids temperature was 2–5-fold times higher in the roto-aerated dryer than in the conventional rotary dryer. Moreover, the drying rate in the new dryer was up to 18-fold higher than those obtained in the conventional rotary dryer at the same operating conditions.

All our previous works with roto-aerated dryer were performed with fertilizers. We had not yet tried this new equipment for food drying. Thus, in the present work, in order to evaluate the viability of the use of this new dryer in the dehydratation of acerola residue from the fruit processing industry, we study the behavior of this new equipment (in a new hybrid configuration) in the drying of this fruit residue, considering its use as food supplementation. Hence, the effects of the process variables on the content of bioactive compounds had to be also investigated.

Considering that pre-treatments can be used to reduce the initial moisture content or to modify the fruit tissue structure in a way that the drying time can become faster, in this work the effect of a pre-treatment with ethanol (Braga et al., 2010) on the drying of acerola residues, has also been investigated. Ethyl alcohol has been chosen because it is a well accepted organic compound in the food industry, being considered as a safe substance (Sun-Waterhouse et al., 2013; Herppich et al., 2015). To ensure proper processing, a detailed characterization of the acerola residues has also been performed in this work.

2. Experimental methodology

2.1. *Characterization of the material*

The residues of acerola used in the experiments came from industrial pulp and juice processing (by Fruteza, a food processing company located in São Paulo State, Brazil). In this extraction process the machines were cleaned to avoid contamination with other materials. The residue of acerola, consisting of kernels and shells, was collected after extraction of the fruit pulp. The material was packaged in portions of approximately 1000 g and then frozen at −18 °C. The samples were removed from the freezer and placed in a refrigerator at 5 °C to thaw 12 h prior to drying.

The moisture content of the product was determined by the oven method at 105 ± 3 °C for 24 h. The ashes content was measured using the method in which the material is incinerated in a muffle at 500 °C for 3 h. To determine the pH of the residue, 15 g of the crushed acerola sample were mixed with 100 mL of distilled water and stirred for 30 min. After that, the solution was centrifuged and the pH of the supernatant was