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Drying of aloe vera puree using hot air in combination with far-infrared radiation and high-voltage electric field: Drying kinetics, energy consumption and product quality evaluation

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ABSTRACT

In this work, aloe vera puree was subject to hot air drying with/without the application of far-infrared radiation (FIR) and high-voltage electric field (HVEF). The puree was dried at various air velocities (0.2, 0.6 and 1 m/s), drying air and controlled surface temperatures (50, 60 and 70 °C) as well as high-voltage electric field strengths (0, 1.88 and 3.75 kV/cm). Comparative evaluation of the drying kinetics, specific energy consumption (SEC) and quality (in terms of color, aloin, total polysaccharides and acemannan contents as well as microbial counts) of the products undergone different drying processes was made. Electric field strength had a significant effect on the drying kinetics, SEC and quality of the dried product. On the other hand, HVEF exhibited a dominant effect on the drying kinetics only at a lower air velocity (0.2 m/s). Application of HVEF could significantly reduce the SEC of the drying process at an air velocity of 0.2 m/s. The optimum condition for aloe vera puree drying using hot air in combination with FIR and HVEF was the use of an air velocity of 0.2 m/s, temperature of 70 °C and high-voltage electric field strength of 3.75 kV/cm.

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1. Introduction

Aloe vera (*Aloe barbadenis* Mill.) is a perennial plant in the family Aloeaceae (Chang et al., 2006). Its fleshy leaves are covered with spikes and its main component is water, accounting for approximately 98.5–99.5% of the plant (Mcanalley, 1993). The products of aloe vera can be divided into 2 types, namely, aloe latex and aloe gel. Aloe latex is derived from the outer skin of the leaves and is composed of hydroxyanthracene derivatives such as anthraquinone glycosides aloins A and B (Saccu et al., 2001). Aloe gel, on the other hand, is taken from the inner part of the leaves (Reynolds and Dweck, 1999).

Aloin is generally considered a toxic contaminant in aloe vera when being used in food and cosmetic products (Gutterman and Chauser-Volfson, 2000). Removal of aloin is essential for upgrading the quality of aloe products. The presence of polysaccharides, which account for most of the dry matter of parenchymal tissues of aloe vera, is, on the other hand, desirable. Polysaccharides in aloe vera consist of two main types: acemannan (reserve polysaccharides rich in mannose), which is

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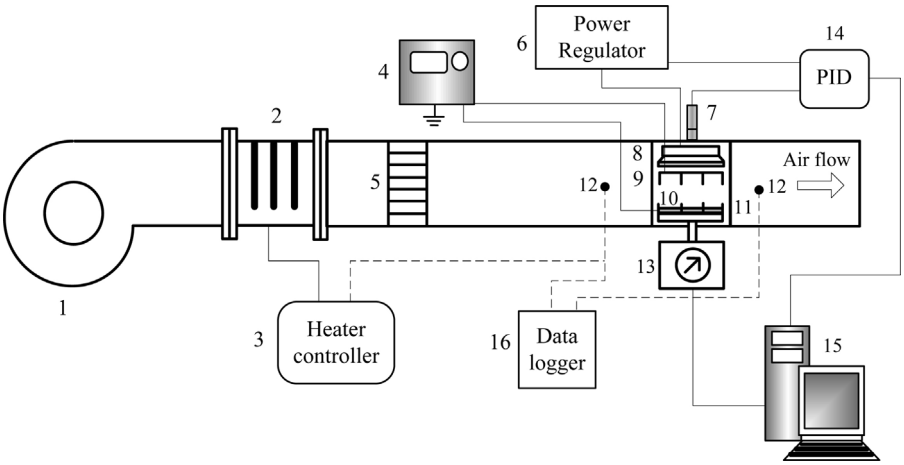

Fig. 1 – Schematic diagram of combined hot air dryer with FIR and HVEF. (1) Blower; (2) electric heater; (3) heater controller; (4) high-voltage power supply; (5) flow straightener; (6) power regulator; (7) infrared temperature sensor; (8) far-infrared radiator; (9) anode electrode; (10) sample holder; (11) cathode electrode; (12) thermocouples; (13) load cell; (14) PID controller; (15) computer; (16) data logger.

found inside the cell protoplasts; and a wide variety of polysaccharides that form the network of the cell walls, which is mainly constituted of pectic substances, cellulose and also hemicelluloses (Femenia et al., 1999, 2003; Chang et al., 2006). Although acemannan is an active and desirable substance of aloe vera, the determination of this compound is nevertheless not straightforward, especially in an industrial setting.

Aloe vera is highly perishable and deteriorates rapidly after harvesting, hence the need to apply an appropriate post-harvest technology to prolong its shelf life. The most common techniques that have been used to preserve aloe vera are hot air drying and spray drying. (Miranda et al., 2010; Cervantes-Martínez et al., 2014). These drying techniques, however, cause significant quality degradation, either in terms of the physical or nutritional quality, of aloe products (Gulia et al., 2010). Energy consumption is another issue that deserves significant attention.

Among alternatives that can be applied to alleviate the above-mentioned limitations of hot air drying, far-infrared radiation (FIR) has received much attention. Radiation energy penetrates through a product and is converted into heat (Ginzburg, 1969), causing the product to be rapidly and uniformly heated without heating the surrounding air. As a result, the energy consumption of FIR-assisted drying processes is noted to be lower compared to that of a conventional hot air drying. Many researchers have successfully applied FIR to assist the drying process of a wide array of agricultural products such as paddy (Meeso et al., 2008), banana (Swasdisevi et al., 2007, 2009), onion (Wang, 2002) and peach (Wang and Sheng, 2006).

High-voltage electric field (HVEF) has also been widely applied in food processing. In terms of drying, HVEF-assisted drying has been successfully applied to enhance the drying rate of rough rice (Cao et al., 2004), spinach (Bajgai and Hashinaga, 2001), potato slabs (Chen and Barthakur, 1991) and rapeseeds (Basiry and Esehaghbeygi, 2010). The occurrence of the so-called corona wind as a result of electricity-induced ionization helps reduce the interface resistance to heat and mass transfer and hence an enhanced drying rate, especially during the constant drying rate period. Since corona discharge can occur at room temperature and atmospheric pressure, HVEF-assisted drying can be implemented at a lower temperature so as to avoid the thermal damage the drying process may cause to heat-sensitive materials. Furthermore, HVEF-assisted drying has been reported to consume less electric power compared to conventional drying techniques.

Despite the aforementioned advantages, there are currently no applications of combined HVEF and FIR to assist hot air drying, which should lead to a significant improvement of the dried product quality as well as reduction of the process energy consumption. Therefore, in this study, hot air drying in combination with FIR and HVEF was used to dry aloe vera puree. The drying kinetics, energy consumption and dried product quality (in terms of color, aloin, total polysaccharides and acemannan contents as well as microbial counts) were then investigated.

2. Materials and methods

2.1. *Materials*

Fresh aloe vera (*A. barbadenis* Mill.) was obtained from a local market (Jatujak market, Thailand). Acibar (a yellow-colored liquid) was first removed from the leaves by cutting the leaves at the base and placing them in a vertical direction for one hour (Miranda et al., 2009, 2010). The leaves were then washed with tap water. Prior to the start of each experiment, the leaves were peeled and sliced by a slicing machine (Savioli, 250S, Rimini, Italy) to the sizes of $0.03 \times 0.03 \times 0.01$ m. The sliced aloe vera was pretreated by soaking in hot water at 80 °C for 2 min to eliminate aloin (Ashleye, 1983). Upon blanching, the aloin content was eliminated by approximately 95%. The blanched slices were blended in a blender (Philips, HR 2067/20, Jakarta, Indonesia) at 4800 rpm for 10 min to prepare a puree. The initial moisture content of the puree (AOAC, 1990) was in the range of 60–62 kg/kg (d.b.).

2.2. *Experimental set-up*

A schematic diagram of the combined FIR and HVEF-assisted hot air dryer is shown in Fig. 1. The dryer consists of a forward-curved blade centrifugal fan (Venz, SC3104, Samutsakorn, Thailand), which was driven by a 0.75-kW electric motor. The air velocity was controlled by an inverter (Fuji, FRN1.5E1S-4A, Tokyo, Japan) connected to the motor. The air was heated by nine electric heaters (each rated at 1 kW) connected to a PID controller (Shinko, JCS-33A-A/M, Osaka, Japan) with an accuracy of ±1 °C. The air temperature before entering the drying chamber was used to determine the amount of heat supplied by the electric heaters. A stainless steel honeycomb, which was used to straighten the air velocity profile, was installed behind the heaters. The drying chamber was made of glass with the dimensions of $0.3 \times 0.2 \times 0.2$ m.

Two FIR heaters (Infrapara, A-2-200, Selangor, Malaysia), each rated at 0.2 kW, and an infrared temperature sensor (Shinko, RD-515-H0, Osaka, Japan) were installed at the top of the drying chamber. The distance between the FIR

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