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Quality assessment of electrohydrodynamic and microwave dehydrated banana slices

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ABSTRACT

In contrast to the inherently energy-efficient electrohydrodynamic (EHD) methods, conventional drying methods are energy intensive. In the present study, comparisons were made between banana slice samples dried by high-voltage-DC powered multiple-point-to-plate electrodes and those dried by microwave (MW). For this purpose, banana slices were dried by an EHD drying system at electric field strengths of 6, 8, and 10 kV/cm and by an MW drying system at specific power levels of 9 and 18 W/g. No constant rate period was observed in the EHD; hence, the entire drying process occurred in the falling rate period, whereas the drying rates of MW-dried samples occurred at a constant rate and during the falling rate periods. Analysis of variance showed that drying method had a significant effect on drying time, rehydration ability, shrinkage, color parameters (L^*, a^*, b^*, *and* ΔE), and consumed energy. The mean values of specific consumed energy for EHD and MW drying methods were 0.34 and 9.66 kJ/g, respectively. In terms of drying time, EHD was not fast; however, its advantages of less energy requirement and great product quality including lower shrinkage, great rehydration ability, and better appearance make it a good choice for drying banana slices.

1. Introduction

The banana fruit comes from a tropical herbaceous plant and is normally consumed fresh; however, the qualities of fresh banana deteriorate rapidly after harvesting. Longer shelf life and significant reduction in the volume of the product are the major reasons for the popularity of dried food material. Thermal damage incurred to a product during drying is directly proportional to the temperature and time involved. Higher temperatures and longer drying times associated with conventional drying may cause serious damages to such quality attributes of the product as flavor, color, nutrients, reduction in bulk density, and rehydration ability of the dried product (Lin, Durance, & Scaman, 1998).

EHD drying is a method of inducing electric wind that is generated by gaseous ions under the influence of a high-voltage electric field (Singh, Orsat, & Raghavan, 2012). The drying rate in EHD depends on the strength of the electric wind impinging on the wet material being dried to produce turbulent, vortex like motions, thereby enhancing the mass transfer rates of volatile components such as liquids (Hashinaga, Bajgai, Isoble, & Barthakur, 1999). The ionic wind velocity induced in terms of EHD set up can be calculated from the following equation derived from the conservation of energy and Gaussian laws (Cross, 1979). The principal mechanism in EHD drying is based on convective heat without the need for direct heat application. This makes it useful for drying heat sensitive materials. The enhancement in mass transfer rate could be attributed to the electric wind induced by EHD as the main driving force. The air ions, which originated from a small region around the needle points, are accelerated by the applied electric force. Momentum is transferred from the ions to the air molecules. This causes the air movement as a whole which constitutes the electric wind. The impingement of this wind on wet materials produces an impact and thus, enhances mass transfer rates of water through increased turbulence. The difference in the pressure of vapor in the ambient air and the ambient close to EHD set up, causes migrate moisture (Chen & Mujumdar, 2002).

Chen, Barthakur, and Arnold (1994) investigated the effects of applying a high voltage electric field (5.25 kV/cm) on the drying characteristics of potato slices. Results showed that the drying rate of potato slices using a single point-to-plate corona discharge electrode system was enhanced by 2.1–2.5 times depending on the slice thickness compared to those dried in the ambient air and, further, that no negative effects were observed on product quality. Hashinaga et al. (1999) studied the effect of AC high voltage electric field on the drying characteristics of apple slices. Results showed

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Nomenclature

V_i	initial volume, mm^3
V_f	final volume, mm^3
ΔV	volume change
a^*	redness
b^*	yellowness
L^*	visual lightness
ΔE	total color change
I	consumed current, A
V	voltage of power supply, V
ϕ	angle of phase variance, deg.
m_i	initial mass, g
m_f	final mass, g
t	time interval, s
E_c	consumed energy, J/g
W_r	rehydration ability, g/g
W_t	weight of rehydrated sample, g
W_d	weight of dried sample, g
E	electrical filed strength, kV/cm

that, compared to the ambient air drying system, the EHD accelerated the initial drying rates of apple slices to almost 4.5 times. The EHD drying characteristics of agar gel were investigated by Isobe, Barthakur, Yoshino, Okushima, and Sase (1999). The system used in their study consisted of a DC power supply, a single point overhead electrode, and an aluminum dish filled with agar gel which acted as the grounded plate electrode. Their results showed that the EHD drying kinetics was highly linear with a drying rate about 3 times faster than the control ambient air drying system. The drying rate and germination parameters of rapeseeds treated in a high voltage electrostatic field were investigated by Basiry and Esehaghbeygi (2010). Their results revealed that the electrostatic field had a significant effect on decreasing the rapeseed moisture content. The average drying rate of electrostatic fields for 8, 9, and 10 kV over 270 min increased by 1.78, 2.11, and 2.47 times, respectively, compared to that of the control. Esehaghbeygi and Basiry (2011) compared oven dried tomato slices treated in a high-voltage electrostatic field (HVEF) and ambient air dried samples. They reported that tomato slices dried by an EHD system which consumed only 16.5 mJ/g of electric power exhibited a better appearance with a lower surface temperature than those dried either in ambient air or in an oven. Alemrajabi, Rezaee, Mirhosseini, and Esehaghbeygi (2011) investigated the effects of drying by EHD and oven on carrot slices to find that the EHD-treated carrot slices exhibited less shrinkage and better appearance than the oven-treated ones.

MW drying has got popularity as an alternative drying method for a wide variety of food products such as fruits, vegetables, snack foods, and dairy products. Microwaves are electromagnetic waves in the frequency range of 300 MHz to 300 GHz, generated by a magnetron type vacuum tube. Electromagnetic energy can be absorbed by water that is based on the transformation of alternating electromagnetic field energy into thermal energy by affecting the polar molecules of a material (Maskan, 2000). The most important characteristics of MW heating is volumetric heating, because the waves can penetrate directly into the material to provide fast and uniform heating throughout the whole product (Mullin, 1995). In this method, heat is generated throughout the material, leading to faster heating rates, compared to conventional

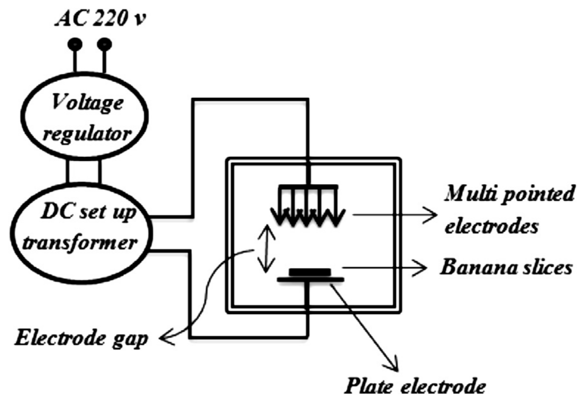

Fig. 1. A schematic of the multiple points to plate electrohydrodynamic (EHD) system.

heating where heat is usually transferred from the surface to the interior (Gowen, Abu-Ghannam, Frias, & Oliveria, 2006).

Studies have been conducted on the drying characteristics of fruits and vegetables treated by MW and MW hot air as well as MW-vacuum drying of such products; apple (Krokida & Maroulis, 2001), garlic (Sharma & Prasad, 2001), parsley (Soysal, 2004), coriander (Kathirvel, Naik, Gariepy, Orsat, & Raghavan, 2006, pp. 1–16), spinach (Ozkan, Akbudak, & Akbudak, 2007), seedless grape (Kassem, Shokr, El-Mahdy, Aboukarima, & Hamed, 2011), pineapple (Botha, Oliveira, & Ahrne, 2012), and foodstuff (Malafronte et al., 2012). In spite of these studies, no published report is found in the literature on the comparative evaluation of drying attributes of fruits and vegetables treated by EHD and MW drying methods. In the present study, we aim to investigate and compare the drying kinetics, rehydration ability, shrinkage, color parameters, and specific consumed energy for dried banana slices subjected to both EHD and MW drying.

2. Material and methods

2.1. Sample preparation

Banana samples with an initial moisture content of 2.75–3 g/g dry weight were purchased from a local market during spring 2011 and stored in the refrigerator at 4 °C. The moisture content of each sample was measured using the oven drying method at 103 °C for 24 h (AOAC, 1990). Prior to the drying experiments and after 4 h stabilization at the laboratory temperature (25 °C), the samples were hand peeled and sliced to pieces of 3 mm thick using a sharp knife on a cut board. In order to select samples of the same stiffness, *Fruits Stiffness Tester* (model OSK-10576 Ogawa Seiki, Japan, accuracy 0.01 kg) was used. The samples were weighed rapidly at regular time intervals using an electronic digital balance (*AND*, model GF-400, Japan, accuracy 0.001 g) to determine drying rate. All the experiments were carried out at the laboratory temperature (25 °C) with a relative humidity of 0.3 g/g. An ultrasonic humidifier equipped with a microcontroller was used to adjust and control the relative humidity of the isolated drying room wherein the experiments were conducted. The ambient relative humidity was measured by a sensor (*Philips* H8302 model) with an accuracy and linearity of ±2% full scale for an operating span of 0.2–0.95 g/g RH.

A complete randomized design was used with three replications and statistical analyses were accomplished using the MINITAB (State College Pennsylvania; Minitab Inc.) and MSTAT-C (Michigan State University). Means were compared using the least significant difference (LSD) test ($P < 0.05$). In order to investigate the effects of the two drying methods on sample quality attributes, an