Application of high voltage electric field (HVEF) drying technology in potato chips

Yaxiang Bai*, Hua Shi, Yaxin Yang
School of Science, Dalian Ocean University, Heishijiao Street, Dalian, China

E-mail: Byx0671@163.com

Abstract. In order to improve the drying efficiency and qualities of vegetable by high voltage electric field (HVEF), potato chips as a representative of vegetable was dried using a high voltage electric drying systems at 20°C. The shrinkage rate, water absorption and rehydration ratio of dried potato chips were measured. The results indicated that the drying rate of potato chips was significantly improved in the high voltage electric drying systems. The shrinkage rate of potato chips dried by high voltage electric field was 1.1% lower than that by oven drying method. And the rehydration rate of high voltage electric field was 24.6% higher than that by oven drying method. High voltage electric field drying is very advantageous and can be used as a substitute for traditional drying method.

1. Introduction
Drying is defined as a process of moisture removal due to simultaneous heat and mass transfer. It is also a classical method of food preservation, which provides longer shelf-life, lighter weight for transportation and smaller space for storage [1]. It has been used for a long time to preserve fruits, vegetables, fish and shrimp etc in many areas of the world [2, 3]. Dried vegetables and fruits products and dried yoghurt has been used in food industry as an ingredient or protein enrichment like confectionery or bakery industry [4, 5]. Besides, dried shrimp and dried shark fin are some of the more popular items that have gained wide acceptance in the US and European markets.

At present, the conventional drying processes of vegetables and fruit are based on convective, radiative, conductive, dielectric heat, superheated steam, and lyophilization, which have been thoroughly discussed. These energy-intensive methods require heat to be applied externally or removed from the drying material while the liquid component in it undergoes a phase change. Osmotic drying does not involve a phase change, and de-watering from cellular materials occurs by applying a hydrostatic pressure different across the semipermeable cell membranes. The fluidized bed drying consists of passing hot air through a bed of the material converted into a fluidized state. In acoustic drying, mass transfer enhancement is brought about by ultrasonic vibrations which also produce heat. Since high temperature dryings usually degrades color, flavor, texture, and nutrients of food [6], non-thermal drying is of importance in industries where heat-sensitive materials are manufactured.

However, there is growing interest in the application of non-thermal processing of food and similar materials. High voltage electric field (HVEF) method is a novel non-thermal technique of drying and is being developed recently [7-10]. Since corona discharge can be produced at room temperature and

* To whom any correspondence should be addressed.
atmospheric pressure, the technique is particularly attractive for low-temperature applications. Compared with hot air drying systems, high voltage electric field drying systems offer lower food production costs as well as superior quality in terms of physiochemical properties such as color, shrinkage, flavor, and nutrient content. Compared with convective and freeze drying, High voltage electric field drying systems have a simpler design, which consumes less energy [11, 12]. Several earlier studies have demonstrated the effectiveness of high voltage electric field drying. Some have even been applied to food preservation with great success. For example, these include the drying of cookie dough, potato slabs, apple slices and spinach, as reported by a recent review by Bajgai et al. [7]. Thus, it shows great potential for bulk and industrial drying applications.

At present, there are few reports available on high voltage electric field drying potato chips. The objectives of this research were to explore a method for potato chips drying. The effects of high voltage electric field and oven drying on potato chips’ quality in terms of shrinkage ratio, water absorption and rehydration ratio were investigated and compared.

2. Experimental setup and procedure

2.1. Experimental setup
The experimental setup for high voltage electric field drying is shown in figure 1.

![Diagram of high voltage electric field drying](image)

**Figure 1.** Diagram of high voltage electric field drying.

It consisted of a vertically mounted electrode with multiple pointed needles projected to a fixed horizontal grounded metallic plate, on which the potato chips to be dried are placed. The distance between the high-voltage electrodes and the grounded electrode was 9 cm. The sharp points of 25 needles were fixedly connected to a DC high-voltage power source. To set the desired high-voltage parameters for high voltage electric field drying, the power source was connected to a voltage regulator, with the voltage adjustable range from 0 to 60 kV by a controller. The grounded plate electrode was a 40×35 cm rectangular stainless steel plate. The apparatus was placed in a stainless steel chamber, the temperature and relative humidity of which were controlled. All the samples were spread in single layer on the grounded plate electrode.

2.2. Experimental materials
Fresh potato was purchased from the local market near Dalian Ocean University, China. It was washed with tap water and the rectangle slices of 4 cm in length, 4 cm in width and 4 mm in thickness were
cut using fine edged knife. The slices were blanched for 3 min in boiling water and followed by cooling in tap water. Water left on the surface of the slices was soaked by blotting paper. The initial weight of the slices was taken and they were subjected for drying. High voltage electric field drying was carried out at 20 °C and 36% relative humidity. Slices were also dried using oven at 60 °C and ambient at 20 °C. Moisture content of potato slice was determined at one hour intervals using a digital electronic balance. Potato slices also were dried in an oven at 80 °C until constant weight and the equilibrium moisture content was determined.

2.3. Shrinkage measurement
The Shrinkage determination was made by manually measuring the sizes (length, width and thickness) of dried potato slices samples obtained from different drying processes (High voltage electric field, oven and ambient air drying) using a vernier caliper. The equivalent spherical diameter of each sample was then determined and compared. Ten samples were taken for measurement for each experimental condition. All experiments were performed twice. Shrinkage was calculated using the following equation:

\[ \text{Shrinkage} = \frac{Z_0 - Z_f}{Z_0} \times 100\% \]  

Where \( Z_0 \) and \( Z_f \) are the potato slices volume of each group at the beginning and at the end of each drying experiment, respectively.

2.4. Water absorption measurement
The water absorption was determined by soaking 10.00 g of dried potato slices on a dry weight basis in 100 ml distilled water at ambient conditions for up to 1 h. The soaked potato slices were blotted with a paper towel every 10 min to remove excess water. They were then weighed and placed back into the soaking water. Water absorption value was expressed in percentage and calculated as grams of water absorbed per 100 g of dried potato slices through the following formula.

\[ \text{Percentage water absorption} = \frac{m_g - m_0}{m_0} \times 100\% \]  

Where \( m_0 \) and \( m_g \) are the weights of dry and soaked potato slices, respectively.

2.5. Rehydration ratio measurement
The rehydration potential of potato slices dried through high voltage electric field, oven, and ambient air was evaluated by immersing them in hot water at 100 °C. The samples were drained, and their weights were measured by a digital electronic balance at 10 min interval for 1 h. The incremental mass due to absorbed water was then calculated as the degree of rehydration per 100 g of dried potato slices expressed as follows:

\[ \text{Percentage rehydration ratio} = \frac{m_g - m_0}{m_0} \times 100\% \]  

Where \( m_0 \) and \( m_g \) are the weights of dry and boiled potato slices, respectively.

3. Results and discussion

3.1. Influence of different drying conditions on drying rate
The drying rate curves of potato slices treated by high voltage electric field, oven, and ambient air drying are shown in figure 2. The drying rate of potato chips was significantly improved in the high voltage electric field drying systems. The average rates of high voltage electric field, oven, and ambient air drying from the first to the fifth hour were 15.2, 12.1, and 2.7 mg min\(^{-1}\), respectively. High voltage electric field drying as a novel non-thermal technique can dry potato slices samples at a low
temperature because of its unique drying mechanism. In the process, the needle electrode produces corona wind (resembling a round jet) that impinges and removes moisture from the surface of potato slices.

3.2. Influence of different drying conditions on shrinkage

During drying, foods undergo volume changes either by shrinkage (due to the removal of water from the drying potato slices) or by expansion (due to gas generation or pore formation) [13]. Different drying techniques thus provide different degrees of volume changes. Normally, the fibers shrink as they lose moisture during the drying process.

![Figure 2. Drying rate of high voltage electric field, oven and ambient air drying for potato slices.](image)

![Figure 3. Effect of different drying methods on the shrinkage ratio of dehydrated potato slices.](image)

Figure 3 shows the results of shrinkage of potato slices that underwent different drying methods. Shrinkage was found to be lower for high voltage electric field than for oven. The final shrinkage values for high voltage electric field and ambient air drying were 7.8% and 7.3%, respectively, while it was 8.9% for oven drying. This result resembles the shrinkage in radish slices [14]. Lesser shrinkage in potato slices dried under high voltage electric field was observed. This shows that high voltage electric field significantly reduces shrinkage. Oven drying resulted in extensive shrinkage, which might be associated with cellular collapse probably due to heat damage of the wall and cell membrane [15].

3.3. Influence of different drying conditions on water absorption

The water absorption curves of potato slices treated by high voltage electric field, oven, and ambient air drying are shown in figure 4. According to the results, high voltage electric field-dried potato slices absorbed more water compared with oven-dried samples when they were soaked in water at 20 °C for 1 h. The water absorbed by the high voltage electric field-dried sample was 268 g/100 g, which is 21 g/100 g more than the water absorbed by oven-dried samples on a dry weight basis.

3.4. Influence of different drying conditions on rehydration rate

Figure 5 illustrates the rehydration behavior of dried potato slices samples obtained from different drying methods at a rehydrating temperature of 100 °C. It was found that high voltage electric field-dried potato slices absorbed more water compared with oven-dried samples when they were soaked in water at 100 °C. The water absorbed by the high voltage electric field-dried sample was 494.6 g/100 g,
which is 24.6 g/100 g more than the water absorbed by oven-dried potato slices, on a dry weight basis. High voltage electric field-dried potato slices also showed better rehydration than oven-treated samples. The high temperature used in oven drying might be the factor enabling oven-treated potato slices to hold less water compared with high voltage electric field and ambient air-dried samples.

**Figure 4.** Effect of different drying methods on the water absorption of dehydrated potato slices.  
**Figure 5.** Effect of different drying methods on the rehydration rate of dehydrated potato slices.

**4. Conclusions**

High voltage electric field drying as a novel technique can dry potato slices samples at a low temperature because of its unique drying mechanism. Thus, the shrinkage rate of potato slices dried by high voltage electric field is lower, and their water absorption and rehydration rate are higher compared with oven drying. Furthermore, as high voltage electric field is a non-thermal technique, no heat energy is lost and energy can be saved significantly. Drying temperature had significant influences on the drying rate, shrinkage, water absorption, and rehydration rate of dried potato slices samples. The drying rate and shrinkage of dried potato slices samples increased with drying temperature, while their water absorption and rehydration ratio decreased with drying temperature.

**References**

[1] Ertekin C and Yaldiz O 2004 *J. Food Eng.* 63 349
[2] Pabis S and Jaros M 2002 *Biosyst. Eng.* 81 201
[3] Duan X, Zhang M and Li X L 2008 *Drying Technol.* 26 413
[4] Leonid A B, Vladimir P G, Andrew V B, Alexander M L, Valeriy L and Vladimir A K 2006 *J. Food Eng.* 74 410
[5] Hayaloglu A A, Karabulut I, Alpaslan M and Kelbaliyev G 2007 *J. Food Eng.* 78 109
[6] Wall R, Bindu J and Howard J J 2001 *J. Applied Ecol.* 38 339
[7] Bajgai T R, Vijaya Raghavan G S and Hashinaga F 2006 *Drying Technol.* 24 905
[8] Lai F C and Wong D S 2003 *Drying Technol.* 21 1291
[9] Bai Y X, Li X J, Sun Y and Shi H 2011 *Int. J. Appl. Electrom.* 36 217
[10] Ramachandran M R and Lai F C 2008 *Drying Technol.* 28 1477
[11] Bai Y X and Sun B 2011 *J. Food Process Pres.* 35 891
[12] Alemrajabi A A, Rezaee F, Mirhosseini M and Esehaghbeygi A 2012 *Drying Technol.* 30 88
[13] Namsanguan Y, Tia W, Devahastin S and Soponronnarit S 2004 *Drying Technol.* 22 759
[14] Bajgai T R and Hashinaga F 2001 *Drying Technol.* 19 2291
[15] Valle J M, Del A V and Leon H 1998 *Food Res. Int.* 31 557