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Electrohydrodynamic drying (EHD) of wheat and its effect on wheat protein conformation

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ABSTRACT

This study investigates the electrohydrodynamic drying characteristics of wheat and its effect on the conformation of wheat protein using Fourier Transform Infrared Spectroscopy (FT-IR). A single wire electrode EHD system was used with a set electrode gap of 1.5 cm, applied voltages of 10 kV, 12.5 kV and 15 kV in combination with air cross-flow of velocities 1 m/s, 1.5 m/s and 2 m/s. It was observed that the drying rate of wheat sample was significantly affected by applied voltage and air velocity. The drying rate increased with an increase in air velocity and applied voltage. This study also showed that wheat protein conformation was significantly affected by EHD drying. In the analysis of the Amide I region (1720 −1580 cm^{-1}) of wheat protein, FT-IR spectra showed distinct valleys at 1682–1686 cm^{-1} (β-sheets), 1674 cm^{-1} (β-sheets), 1664–1667 cm^{-1} (turns), 1654–1657 cm^{-1} (α-helices), 1651 cm^{-1} (α-helices), 1645 −1647 cm^{-1} (Random coils) and 1633–1634 cm^{-1} (β-sheets). Peak fitting using Gaussian band shapes suggested that exposure to electric field influenced the hydrogen bonding pattern of wheat protein resulting in shifts between low and high frequency bands which further supported these results.

1. Introduction

Drying is an important unit operation in the food industry primarily used for reducing the moisture content of the food. Reduction in moisture improves the shelf life and also moderates the transportation costs of food products (Singh, Orsat, & Raghavan, 2012). Traditionally, drying is conducted by exposing the food to high temperatures and this exposure results in various compositional/structural changes, both desirable and undesirable (Bajgai, Raghavan, Hashinaga, & Ngadi, 2006; Raghavan et al., 2005; Singh et al., 2012). Moreover, conventional drying techniques use large quantities of fossil fuels to generate the required thermal energy, which also has a negative environmental impact (Raghavan et al., 2005).

Growing concerns over recent climatic changes and environmental impacts of application of fossil fuels has instigated the demand from both the public and the government agencies for development of green processing techniques in all industrial sectors (Bajgai et al., 2006). For food industries meeting the environmental impact guidelines and consumer demand for foods with better nutritional and sensory characteristics has led to the acceleration in the development of novel processing techniques (Singh et al., 2012) which can be classified into two categories, minimally thermal and non-thermal processing methods (Mertens & Knorr, 1992).

Electrohydrodynamic (EHD) drying is one of the non-thermal, novel processing techniques with a lot of potential for wide applications in the food industry. This process involves the use of corona wind, which is generated when a high voltage is applied to an electrode of very small radius of curvature (Chen, 2003; Yaxiang, Yucai, & Xinjun, 2010). The ions produced around the electrode have either excess or deficiency of electrons and are bound with the coulomb forces acting between them. These ions when emitted from the charged electrode collide with neutral air molecules, which get charged due to the high electric field and migrate towards the ground/neutral electrode causing an ionic wind also termed as 'corona wind'. This corona wind enhances the mass transfer by disrupting the saturated vapor layer over the food surface paving a path for the moisture to escape (Singh et al., 2012).

When food products are subjected to processing conditions such as drying, frying, freezing, etc., both wanted and unwanted changes

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to its constituents such as protein, carbohydrates and lipids take place. Of all food constituents, proteins are one of the most important with respect to the impact on consumer's health. It is well known that characteristic physico-chemical properties of all proteins are dependent on their structural conformation (Arntfield & Murray, 1981; Singh, Munshi, & Raghavan, 2013). Amino acids, which are the building blocks of a protein; form a peptide bond with each other by giving out a water molecule and this linear arrangement gives a protein its 'primary structure' (Amadei, Linssen, & Berendsen, 1993), which is the first of the four levels of structure. Depending on the amino acids forming the linear structure, the protein folds into helices, β-sheet and turns which are defined as the 'secondary structures' (Pelton & McLean, 2000; Surewicz, Mantsch, & Chapman, 1993). The 'tertiary structure' is formed because of various bonds between the amino acid chains including the hydrogen bonds and di-sulphide bonds giving the protein a three dimensional structure. The 'quaternary structure' is observed in large protein molecules that are formed when multiple protein subunits come together to form a large three-dimensional structure. The destruction of these protein structures is known as protein denaturation.

When food proteins are subjected to an external stress including thermal, electrical, chemical, pressure etc., they undergo conformational changes that lead to variation in their functional properties (Arntfield & Murray, 1981; Singh et al., 2013). FT-IR spectroscopy is widely employed to study protein structures. The protein sample absorbs the infrared radiation at specific intensity and wavelength, which when measured gives the structural data of the polypeptide secondary structures of the protein. And when the Fourier transform is used to convert this raw data obtained into a proper spectral data, it is called an FT-IR spectrum (Haris & Severcan, 1999; Jackson & Mantsch, 1995). The structural units present in the protein give rise to a total of 9 distinct regions which are named Amide A, B and I-VII (Kong & Yu, 2007). The secondary structures of the proteins can be analyzed using the Amide I region (1720 cm^{-1}–1580 cm^{-1}) which is responsible for the vibrations of the C═O stretch in peptide linkages and also is the most prominent of all the amide regions (Mangavel, Barbot, Popineau, & Guéguen, 2001). Amide II region of the spectra is caused due to the vibration in the C–N bond stretching and the N–H bond bending in the protein structure (Georget & Belton, 2006). Several researchers have conducted FT-IR analysis on various food proteins including the wheat protein (Belton, 1999; Belton et al., 1995; Georget & Belton, 2006; Wang et al., 2001). The objective of this study was to investigate the effect of EHD on drying characteristics of wheat and evaluate its effect on the conformation of wheat protein using FT-IR.

2. Materials and methods

2.1. Sample preparation

Wheat sample of moisture content around 8 g/100 g dry basis (d.b.) was procured from the local market. The wheat was cleaned and later conditioned by addition of water to increase its initial moisture content to 20 g/100 g (d.b.). This sample was then stored in the refrigerator at 4 °C.

2.2. Experimental setup

The schematic diagram of the EHD setup used for the present study is shown in Fig. 1. The setup consisted of a sample compartment made of Plexiglas of the following dimensions; 28.1 cm long, 11 cm wide and 8 cm high. It was connected to a blower at one end, which forced the air into the compartment at different velocities (1 m/s, 1.5 m/s and 2 m/s) set manually before the start of the experiment. The sample container was also made of Plexiglas of dimensions; 10 cm long, 2.5 cm wide and 2.5 cm deep. The base of the sample container was made of aluminum, which acted as the ground electrode. The sample compartment also enclosed a vertically mounted emitting electrode (copper wire of 0.5 mm diameter), which was suspended above the sample box. The gap between the emitting electrode and sample surface was fixed at 1.5 cm. A direct current at high voltage (positive polarity) was applied to the emitting electrode from a power supply unit, which could provide a maximum voltage output of 30 kV. A data logger recorded the temperature, relative humidity of the ambient air and the change in mass of wheat every minute. The drying experiment was conducted till the moisture content of the sample reduced to 15 g/100 g d.b. and during all the experiments the ambient temperature remained fairly constant, as the lab temperature was controlled but during some experiments the relative humidity showed substantial changes, this change might have contributed to the variability in the data that will be discussed in the following sections.

2.3. Drying experiment

The wheat samples were removed from the refrigerator and kept at ambient temperature till they reached the ambient conditions. About 40 g of wheat samples was used for EHD drying. The drying experiment consisted of 2 factors (air velocity and applied voltage) with 3 levels each (air velocity: 1, 1.5, 2 m/s; applied voltage: 10, 12.5, 15 kV), which were used to generate a full factorial experimental design. The experimental design was developed using JMP software (ver. 10, SAS Institute Inc., Cary, NC, USA). All the experiments were replicated thrice and the data were analyzed. Results from three replicates of the control samples (only air cross-flow) were used as reference to evaluate the drying enhancement with the applied electric field.

2.4. Mathematical modeling

Mathematical modeling of drying kinetics has proven crucial in design, development and optimization of drying systems (Taghian Dinani, Hamdami, Shahedi, & Havet, 2014). In case of EHD drying, engineering challenges involved in development of industrial scale drying systems can be overcome by understanding the relationship between the process parameters and their effect on the overall efficiency of the drying system. Hence, in the present study the effect of the process parameters on the EHD drying kinetics of wheat was evaluated using mathematical models including Newton, Page, Modified Page, Henderson and Pabis and Exponential (Cao, Nishiyama, & Koide, 2004) (Table 1). A wheat sample size of 40 g ± 0.7 g was used for all the experiments. The initial moisture content (20 g/100 g d.b.) of the wheat sample for all experimental runs on a dry basis (d.b.) was estimated by the official method 925.10 of AOAC (2000) using Equation (1).

$$M.C.(d.b.) = \frac{M_w}{M_s} \tag{1}$$

where, M_w is the mass of water in the sample (g); M_s is the mass of the solid in the sample (g). The moisture ratio of the sample was determined using Equation (2).

$$MR = \frac{M_i - M_e}{M_0 - M_e} \tag{2}$$

where, M_0, M_i and M_e are initial moisture content, moisture content