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Application of infrared thermography and dielectric spectroscopy for controlling freezing process of raw potato

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ABSTRACT

Freezing technique is a very useful method for food preservation, although it sometimes produces damages in the product. The distribution of temperatures of raw potato was measured during the freezing operation by using an infrared thermographic camera Thermal Imager Optris PI160. Moreover, volume, moisture and water activity were measured before and after the freezing process. Cryo-SEM was also used to analyze the microstructure of fresh, frozen and thawed potato. The dielectric spectra of potato samples were measured before freezing and after defreeze, using an Agilent 85070E Open-ended Coaxial Probe connected to a network analyzer Agilent E8362B in the frequency range from 500 MHz to 20 GHz. The aim of this work was to monitor the temperature of potato surface during the freezing operation and to determine the water chemical potential and the structural changes of potato during this process, in order to determine the water motion throughout the freezing. The results showed important relations between the heat flux, water chemical potential gradients and structural changes. The paper demonstrated that infrared thermography and dielectric properties can be considered very important nondestructive tools for monitoring the freezing process of potato.

Industrial relevance: The results of this research article are demonstrated to be useful for describing the freezing process of raw potato. Thus, the industrial relevance is clear because two nondestructive techniques have been used for this purpose: infrared thermography and dielectric properties. On the other hand, a microstructural study of fresh, frozen and thawed potato has been made. For all these reasons we are sending to this journal "Innovative Food Science and Emerging Technologies" our results.

1. Introduction

The potato (*Solanum tuberosum* L.) which is grown in over 100 countries throughout the world is one of the staples of the human diet and one of the most important raw materials for the food industry. Potatoes are one of the most important sources of energy and other nutrients including vitamins and minerals (Storey, 2009). Potatoes are industrially processed in a wide range of convenience products (Karlsson & Eliasson, 2003). The dry matter of potato tubers is composed of various substances: starch (15%), sugars, nitrogen compounds, lipids, organic acids, phenolic compounds, mineral substances and non-starch polysaccharides (protopectin, soluble pectin, hemicelluloses, cellulose) (Kita, 2002).

Freezing is one of the most used methods for long preservation of food products, because it results in minimal deterioration of the original flavor, color, texture or nutritional values (Jalté, Lanoisellé, Lebovka, & Vorobiev, 2007) when it is compared with other preservation methods. The quality of frozen foods depends on the size of ice crystals (Li & Sun, 2002a, 2002b). Rapid freezing produces small intracellular ice crystals, while slow freezing forms large ice crystals. Large ice crystals would cause damages to food quality including appearance, sensory properties, textural attributes and nutritional value (Li & Sun, 2002a). Plant tissues (fruits and vegetables), which present a semi-rigid cellular structure, exhibit less resistance to the expansion of ice crystals in volume, thus they are prone to being subjected to the irreversible freezing damage (Li & Sun, 2002a). The freezing damages are also caused by solute concentration in the unfrozen liquid and the osmotic transfer of water from cell interior which determines the dehydration damage. These damages in plant tissues would result in loss of function in cell membrane, disruption of metabolic systems, protein denaturation, permanent transfer of intracellular water to the extracellular environment, enzyme inactivation, and extensive cell rupture (Li & Sun, 2002a).

Until recently, the only method for the detection of ice formation in plant tissues has been the electronic recording of plant temperature using thermocouples and examining the exothermic process, but these detection methods are both difficult and sometimes unreliable (Le Grice, Fuller, & Campbell, 1993; Wisniewski, Lindow, & Ashworth, 1997). Moreover, the thermocouples are inserted into the tissue damaging the cells and leading to solute leakage which itself may become a site for ice nucleation thus creating an artifact (Le Grice et al., 1993; Wisniewski et al., 1997). Recent advances and potential applications

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of Infrared thermography (TI) for food safety and quality assessment such as temperature validation, bruise and foreign body detection, and grain quality evaluation, have been reviewed (Gowen, Tiwari, Cullen, McDonnell, & O'Donnell, 2010). TI is a two-dimensional, non-contact diagnostic technique for measuring surface temperature of materials which can be used in non-destructive quality evaluation (Giorleo & Meola, 2002; Gowen et al., 2010).

Dielectric spectroscopy determines the dielectric properties of a medium as a function of frequency. It is based on the interaction of an electric external field with the sample (Metaxas & Meredith, 1993; Nelson & Datta, 2001); complex permittivity (ε_r) is the dielectric property that describes this interaction (Metaxas & Meredith, 1993; Nelson & Datta, 2001). The real part of complex permittivity is called dielectric constant (ε') and the imaginary part is called loss factor (ε''). The dielectric constant is related with the ability of the food to store energy, and the dielectric loss factor is related to the dissipation of the electric field energy in other kinds of energy such as the thermal one. Several studies reveal that changes in physical state affect dielectric properties (Castro-Giráldez, Fito, Prieto, Andrés, & Fito, 2012; Lyng, Arimi, Scully, & Marra, 2014). Thus, phase transitions probably can cause changes in dielectric properties.

The aim of this study was to monitor the temperature of potato surface and to describe and quantify the water motion during the freezing process by using the infrared thermography and dielectric spectroscopy.

2. Materials and methods

2.1. Previous experiments

It is fundamental to calibrate properly the infrared sensor in order to obtain reliable data of temperature. For this reason, previous experiments were carried out with reference materials in order to obtain a real value of emissivity. Experimental setup consisted of potato sample, distilled water and an aluminum foil. Fresh potato samples (*S. tuberosum* L. cv. Melody) were peeled and cut with a cylindrical core borer in order to obtain cylinders with 20 mm diameter and 10 mm height. Distilled water was placed in a box with a bottom half painted with black color (emissivity close to 1) and the other half was covered with aluminum, although no differences were found between both measurements. The freezing process was carried out from 20 °C until −20 °C with freezing air velocity of 0.45 m s^{-1}. The experiment was carried out by triplicate but only one of them is shown as an example.

A thermographic camera Thermal Imager Optris PI160 with a spectral infrared range of wavelength from 7.5 a 13 μm was used for the experiments. Moreover, different thermocouples (Thermometer model HIBOK 14, sensor type K, sensitivity 39 μV·°C^{-1}, accuracy ±0.1) were used to register the temperature of potato surface, water, aluminum foil and ambient. Fig. 1 shows a scheme of the experimental setup.

2.2. Experimental procedure

Ten fresh potato samples (*S. tuberosum* L. cv. Melody) were tempered at 4 °C before starting the experiment. The samples were peeled and cut with a cylindrical core borer in order to obtain cylinders with 45 mm diameter and 70 mm height. Potato samples were removed from the refrigerator and placed in the freezer (Dycometal, S.L. model ACR-45/87). The freezer was maintained at −20 °C with air velocity of 0.45 m s^{-1}. The air velocity was measured using portable Airflow's TA5 Thermal Anemometer. During the freezing process, the surface temperature was recorded with an infrared thermocamera (Thermal Imager Optris PI160 with 120 Hz frame rate, detector with 160 × 120 pixels), see Fig. 2. The volume of the samples during freezing process was determined by image analysis of the pictures captured with thermocamera every 3 min. The image analysis was made with the software Adobe Photoshop® (Adobe Systems Inc., San Jose, CA, U.S.A.). Moreover, different thermocouples (Thermometer model HIBOK 14, sensor type K, sensitivity 39 μV·°C^{-1}, accuracy ±0.1) were used to

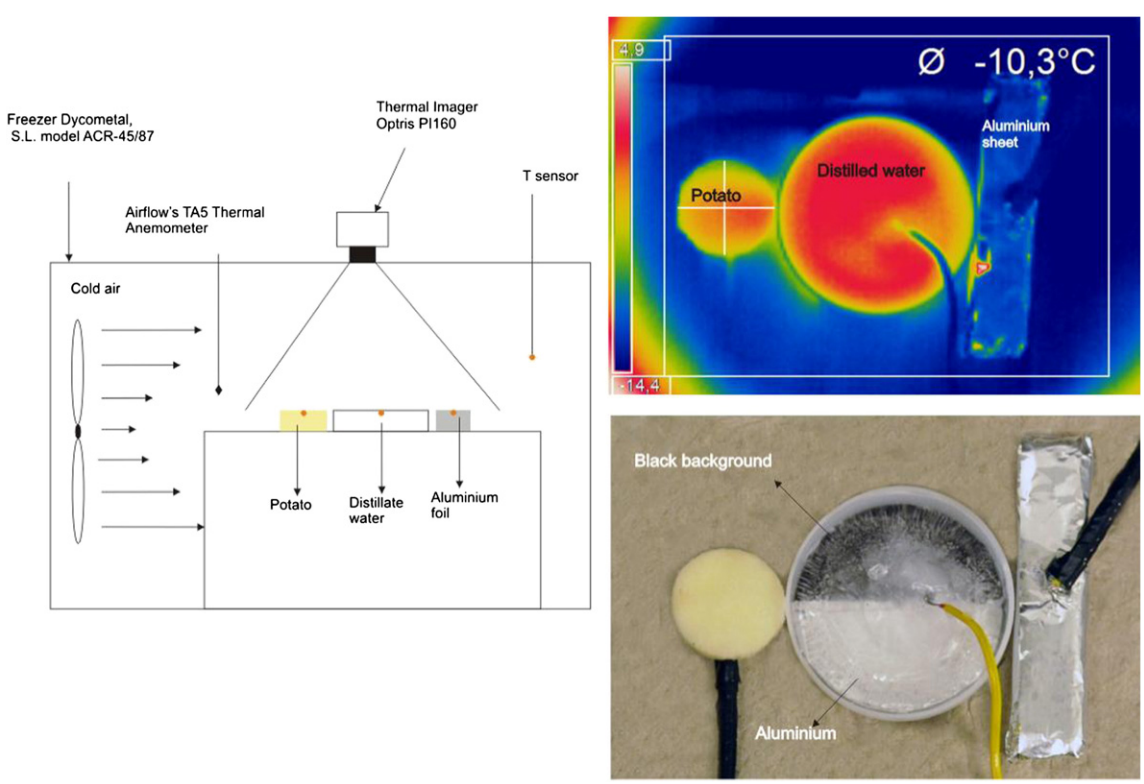

Fig. 1. Previous experimental setup.