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Research Paper

Experiments and modelling of the microwave assisted convective drying of canola seeds

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The heat and mass transfer that occurred during the drying of a 1:1 mixture of two canola seed varieties using combined microwave (MW) and convective drying was studied. A coupled mathematical model was adapted to simulate the physical process. The product was re-wetted to an initial moisture content (IMC) of 18% w.b. and then dried in a microwave oven under MW density of 0.5 W g^{-1}, 1 W g^{-1} and 2 W g^{-1}. Results show that the maximum drying rate increased from $4.3 \times 10^{-5}$to 6.8×10^{-5}kg [water] kg^{-1} [grain w.b.] s^{-1} in the convective drying as the temperature of the inlet air increased from 40 to 60 °C, but it remained constant when MW was combined with convective hot-air. The use of microwave energy during drying of canola seeds resulted in faster drying when coupled with convective drying at low relative humidity.

1. Introduction

The global demand of oilseeds is increasing due to increased pressure from the biodiesel industry. Next to the soybean, the global demand for canola production increased over the last decade, rising from the sixth largest world production in 2004 to the second largest in 2014 with a current total production of 71.5 million metric tonnes (FAO, 2014).

Similar to soybean, canola contains high contents of oil and protein. The small round canola seeds contain 38–45% of oil and 23% of protein (USDA, 2014). Typically the harvest moisture content of canola seed is 12% but it needs to be brought <8% for safe storage (Kandel and Knodel, 2011). In

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order to preserve the viability, canola for seed purposes should be dried at temperatures below 44 °C. Conventional process of air drying of canola takes about 3–4 weeks, which may reduce the quality of canola while it under goes prolonged drying. Hence, a rapid dryer which can bring the moisture to within a safe limit in the shortest possible time is desirable. In a previous study, applying microwave power in conjunction with hot air drying has been shown to lead to higher drying rates when compared with the conventional hot air drying of soybean seeds (Ranjbaran & Zare, 2012).

Correa, Martins, and Christ (1999) observed the increase of viability of canola seeds with higher humidity and a decrease with higher temperatures associated with drying. Kumar, Jain, and Garg (2009) reported that canola seeds can be safely dried at 55 °C whilst retaining up to 90% germination. In order to increase the drying rate while keeping the seeds viable, a hybrid microwave (MW) assisted convective dryer has been used in this study. Hybrid dryers provide more uniform heating and rapid moisture transfer within the product, keeping the product cooler and more viable.

A MW drying study on rapeseeds in a semi-industrial scale with inner emission of microwaves was reported by Lupinska et al. (2009). They observed that the emitted MW energy was totally absorbed by the product dried and that the mechanical expression of liquid water due to the internal pressure gradient was a dominant driving force for moisture removal. The influences of initial moisture content and MW power levels on the mechanical damage of rapeseed were tested. It was found that the MW assisted drying at low power levels can lead to reduced damaged seeds.

Soproni et al. in (2012) found that wheat seeds that had been treated in MW without an airstream resulted in a lower quality product. They also reported a high rate of germination when they applied lower MW densities along with hot airstream. They recommended that a low constant MW power density of around 0.4 W g^{-1} with a hot airstream was the best approach for treating seeds, offering good quality and high rates of germination.

The objectives of this work are to study the effects of MW power density and initial drying conditions of canola seeds in microwave assisted convection dryer with process simulation using a coupled mathematical model of microwave and convective hot-air system. An explanation of the mechanism affecting the rate of drying associated with the temperature and relative humidity of inlet air has been attempted.

2. Materials and methods

2.1. Sample preparation

Two Canadian canola seeds varieties (*Brassica napus and Brassica rapa*) were used in this study and mixed together in 1:1 proportion. The reason behind mixing these two varieties is to study the most case which can meet when stored canola seeds. Usually we found more than one variety in a silo of storage. The initial conditions of the product studied was 18% (w.b.) obtained by adding a calculate amount of distilled water, and thoroughly mixing the grain. Conditioned canola samples were stored in sealed plastic bags in a refrigerator at 5 °C and were equilibrated in sealed bags to the room temperature for 30 min prior to the use in the drying experiments.

The measurement of the moisture content of canola seeds was conducted by drying triplicate 15 g samples at 105 °C for 24 h (ASAE, 1985).

2.2. Thermal properties

Knowledge on thermal properties of an agricultural product is important to study the problems encountered in a drying process. The dielectric properties of foods depend to several parameters such as moisture content of the product, frequency of microwave, temperature of material, the composition and materials structure. Table 1 shows the physical, thermal and dielectric properties of canola used in this study.

2.3. Drying equipment

The drying of canola seeds was performed in a custom made laboratory microwave assisted convective dryer (Fig. 1). The microwave generator operated at 2.45 GHz and the power could be varied from 0 to 750 W. Two Hewlett Packard crystal detectors Model 420A, California, USA monitored the incident and reflected power. The temperature of the canola was measured using an optical fibre probe (Nortech EMI-TS series, Quebec, Canada). Inlet and outlet air temperatures were measured outside the shielded cavity using type-T thermocouples. The mass of the drying sample was measured using a load cell connected to an Imperial Instruments TM-2 signal conditioner (Il, USA). All sensors were connected to an Agilent 34970A Data Acquisition/Switch Unit (CA, USA) connected to a computer. The acquisition and control program was written in Agilent VEE Pro Ver 8.0 (CA, USA). A PID controlled hot air blower provided hot air to the microwave cavity.

2.4. Drying conditions

Canola seeds were processed by either microwave assisted convective drying or by convective drying (hot-air). In these experiments, drying characteristics were monitored and analysed at the initial moisture content of canola seeds 0.18 kg [water] kg^{-1} [grain w.b.]. Processing time was kept constant at 60 min.

3. Modelling

The heat and mass transfer process between canola seeds and the convective air during drying by MW were modelled using the coupled mathematical model described by Hemis, Choudhary, and Watson (2012) and Hemis and Raghavan (2014) but adapted for canola seeds. The system of nonlinear partial differential equations obtained by coupling mass and energy balances was solved in MATLAB™ (MathWorks, MA, USA) using the Crank-Nicolson finite differential method.

The mathematical model was constructed using the following assumptions: uniform initial temperature and