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Industrial-scale radio frequency treatments for insect control in lentils

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ABSTRACT

Radio frequency (RF) treatments are considered to be a potential postharvest technology for disinfesting legumes of internal seed pests such as the cowpea weevil. After treatment protocols are shown to control postharvest insects without significant quality degradation, it is important to scale-up laboratory RF treatments to industrial level applications. A 27.12 MHz, 6 kW RF unit with a built-in forced hot air system was used to conduct industrial scale-up studies. A treatment protocol was designed to provide 100% cowpea weevil mortality combined RF with forced hot air to heat product to 60 °C for 10 min, followed by forced ambient air cooling for 20 min. An electrode gap (14.0 cm) was chosen based on the electric current and heating time, and conveyor belt speed was set to 7.5 m/h. Heating uniformity was evaluated by measuring post-treatment surface temperatures with a thermal image camera and interior temperatures with thermocouples. Changes in moisture content, color and germination were used to evaluate treatment effects on product quality. Finally, the RF system heating efficiency and throughput were calculated. Results showed that heating uniformity and quality of lentils in continuous RF treatment with hot air and movement were acceptable, the average heating efficiency of the RF system was 76.5% and throughput was 208.7 kg/h. The average energy efficiency and throughput of the RF system provided sufficient data to develop an industrial-scale RF process as an alternative to chemical fumigation.

1. Introduction

Lentil (*Lens culinaris*) is an important rotational legume in the north-western United States, especially Washington State (USADPLC, 2010). Disinfestation treatments for agricultural products are necessary to meet postharvest phytosanitary regulations before export to international markets, such as India, Korea, Spain, and Latin American countries (USADPLC, 2007). Since the Montreal Protocol (UNEP, 1992) in 2005 largely banned conventional disinfestation methods using methyl bromide fumigation in developed countries due to damage to the ozone layer, an alternative non-chemical quarantine treatment such as radio frequency (RF) heating is urgently required (Wang and Tang, 2004).

RF heating has been studied for control of different insects for various agricultural commodities (Nelson and Payne, 1982; Nelson, 1996; Tang et al., 2000; Marra et al., 2009; Gao et al., 2010). Lagunas-Solar et al. (2007) showed that RF treatment controlled insects in rough rice with no significant quality changes. Wang et al. (2001, 2002) and Mitcham et al. (2004) developed pilot scale RF treatments for control of codling moth and navel orangeworm in in-shell walnuts, and scaled up the treatment procedure using an industrial conveyorized RF system for disinfesting in-shell walnuts with acceptable product quality (Wang et al., 2006a, 2007a, b). Recently, Wang et al. (2010) reported a RF disinfestation treatment protocol at 60 °C for 10 min to completely control cowpea weevils in legumes (chickpea, lentil and green pea) with acceptable product quality, based on their dielectric properties (Guo et al., 2008, 2010; Jiao et al., 2011a). With RF heating, only 5–7 min were needed to bring the central temperature of 3 kg legumes to 60 °C from room temperature, the heating uniformity was improved by adding forced hot air and movement of samples. However, the previous study was conducted with small amount of samples in a batch mode; studies are needed to prove that this RF treatment is suited for continuous processes that can handle large quantities of legumes in commercial applications.

Heating uniformity is an important consideration in scaling-up any proposed RF treatment protocol. Factors resulting in non-uniform heating during RF treatments include non-uniform

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electromagnetic field distribution and variations of product moisture content and thermal properties (Wang et al., 2007a). Several practical means can be used to minimize non-uniform RF heating, i.e. adding forced hot air to the product surface to reduce the energy exchange between the product surface and surrounding air, sample movement, rotation or mixing during RF treatment and immersing products into water for fresh fruits (Birla et al., 2004; Wang et al., 2006b, 2007a, 2010; Tiwari et al., 2008; Sosa-Morales et al., 2009; Gao et al., 2010). For dry commodities such as lentils, optimizing temperature uniformity during RF treatments by adding hot air and movement along a conveyor belt could be very helpful in ensuring complete insect mortality throughout the bulk of the product.

Industrial-scale RF treatments must maintain product quality. Moisture content, germination and color have been selected as quality parameters to evaluate the quality changes of lentils under improved heating uniformity (Wang et al., 2010). Based on tests of small samples treated in batches, Wang et al. (2010) reported acceptable quality of lentils after RF disinfestation treatments. But for continuous treatments of large amount of samples, the quality changes may be different and need to be determined.

The objectives of the current study were (1) to determine the RF processing parameters (electrode gap and conveyor belt speed), (2) to investigate the RF heating uniformity in lentils, (3) to evaluation the product quality (moisture content, color and germination) after RF treatments, (4) to estimate the heating efficiency and throughput of the RF treatment process.

2. Materials and methods

2.1. RF and hot air heating systems

A 27 MHz 6 kW RF unit (COMBI 6–S, Strayfield International, Wokingham, U.K.) was used to heat the lentils in combination with a customized auxiliary hot air system using a 5.6 kW electrical strip heater and a blower fan (Fig. 1). A conveyor belt system (TOSVERT-130 G2+, Toshiba International Corp., Houston, TX) was built into the RF unit to move the samples at different speeds to simulate a continuous process. A detailed description of the RF system can be found in Wang et al. (2010). Lentil samples were treated in plastic polypropylene containers (0.40 L × 0.23 W × 0.10 H m^3) with perforated side and bottom walls (Fig. 2) to allow hot air to pass through the lentils (George Brocke & Sons, Inc., Kendrick, ID, USA.).

2.2. Determining electrode gap and conveyor belt speed

The height of the top electrode in the RF unit was adjustable to change the electrical current and RF power (Fig. 3), which was provided by Strayfield International, Wokingham, U.K. for the power calibration curve using water loads. The dimension of the top electrode was 69 L × 50 W cm^2, allowing three plastic containers to be heated simultaneously between the electrodes. To develop a continuous RF treatment protocol, the optimal electrode gap and conveyor belt speed was determined first. Three plastic containers filled with 6.4 kg lentils were placed on the stationary conveyor belt between the electrodes to obtain a general relationship between the electrode gap and electric current. An electrode gap range of 13.5–18.0 cm was considered. After setting the electrode gap at 18.0 cm, RF power was turned on and the electric current was immediately recorded. This procedure was repeated until the electrode gap was incrementally adjusted to a minimum of 13.5 cm. Based on the measured electric current, electrode gaps of 14.0, 14.5 and 15.0 cm were selected for subsequent heating tests. With the conveyor belt stationary and without forced hot air, the sample temperature at the geometric center of the middle container was recorded with a FISO optic sensor (UMI, FISO Technologies Inc., Saint-Foy, Quebec, Canada) during RF heating. The time needed for the center temperature of the middle container from ambient temperature (22.3 °C) to 60 °C was recorded. The conveyor belt speed was calculated by dividing the electrode length by the resulting heating time.

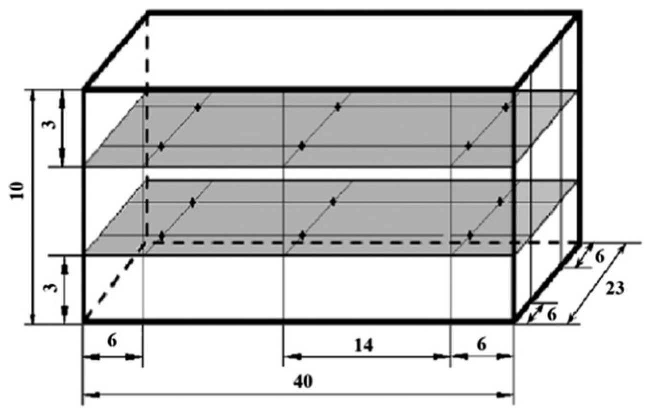

Fig. 2. Dimensions of the plastic container and the location of 12 thermocouples (+) used for temperature measurement (all dimensions are in cm).

2.3. Heating uniformity evaluation

The insect disinfestation treatment proposed by Wang et al. (2010) uses product heating to 60 °C with RF and 60 °C hot forced air, followed by maintenance of the target temperature for 10 min using hot forced air alone. The temperature uniformity of this treatment was evaluated at two points; immediately after the target temperature was reached, and after the 10 min maintenance. To do this, eight containers filled with lentils were placed on the

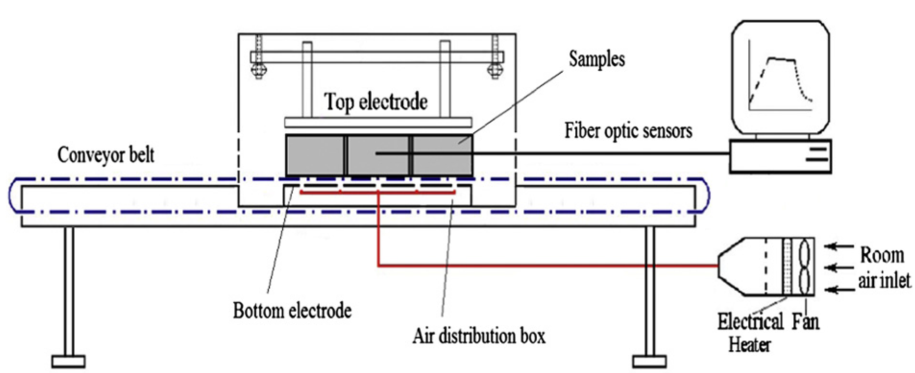

Fig. 1. Schematic view of the 6 kW, 27.12 MHz RF unit with hot air and temperature measurement systems (adapted from Wang et al., 2010).