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Development of thermal treatment protocol for disinfesting chestnuts using radio frequency energy

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ABSTRACT

Methyl bromide fumigation, widely used for disinfesting chestnuts, will be banned in developing countries by 2015 under Montreal Protocol due to its adverse effects on human health and environment. The purpose of this research was to study possible applications of radio frequency (RF) heating for disinfestations of chestnuts to replace chemical fumigation. A 6 kW, 27 MHz free-running oscillator RF system was used to determine the effect of a developed RF treatment protocol on quality of chestnuts. The results showed that the heating time needed only 5.4 min to heat the 2.5 kg chestnuts from 20 °C to 55 °C using RF energy, and 170 min for chestnuts to reach 52.5 °C using hot air at 55 °C and 1.6 m/s. Based on the heating uniformity studies, a RF treatment protocol was finally developed to combine 0.6 kW RF powers with a forced hot air at 55 °C, movement of the conveyor, mixing twice, and holding at 55 °C hot air for 5 min, followed by forced room air cooling through single-layer samples. Quality of chestnuts was not affected by the RF treatments because no significant differences in moisture, protein, fat, soluble sugar, firmness, and color were observed between RF treatments and untreated controls after 8 days at 35 °C, simulating one year of storage at 4 °C. The RF treatments may provide a rapid and environmentally friendly method to replace chemical fumigation for disinfesting chestnuts.

1. Introduction

Since postharvest chestnuts contain high moisture content, rich carbohydrate, and low fat (Chenlo et al., 2009; Vasconcelos et al., 2010; Suárez et al., 2012), infestations with pests and diseases are the major problems in a chestnut storage (Chenlo et al., 2009; Antonio et al., 2011), resulting in high economic losses and short shelf-life. Methyl bromide fumigation has been widely used to disinfest agricultural products, such as chestnuts. However, this chemical fumigation is harmful not only to human health but also the environment. According to the Montreal Protocol, production and applications of methyl bromide will be banned in developing countries, such as in China, by 2015 (UNEP, 1992). It is urgent to develop non-chemical alternative methods to replace methyl bromide fumigation for disinfesting chestnuts.

Non-chemical methods include cold storage, controlled atmosphere, low pressure, irradiation, and thermal treatments for disinfesting agricultural commodities (Heather and Hallman, 2007). Cold storage, controlled atmosphere and low pressure treatments require lengthy exposures, and particular concerns on irradiation are the possibility of inspectors or consumers finding live insects in treated products. Thermal treatments, such as hot air and radio frequency (RF) treatments, have been mainly proposed as physical methods for disinfesting agricultural commodities since they are relatively easy to apply, leave no chemical residues, and may offer some fungicidal activity. A common difficulty with conventional heating methods is the slow rate of heat transfer, resulting in long treatment times (Hansen, 1992). In contrast, RF energy interacts directly with the entire volume of agricultural products and thus provides fast and volumetric heating (Tang et al., 2000). Although potential differential RF heating has been reported between insects and host dry products (Shrestha and Baik, 2013; Wang et al., 2013), there is a need to determine the RF heating uniformity in chestnuts before developing an effective treatment protocol.

Most work on the use of RF energy for disinfestation has focused on fresh fruit, such as cherries (Hansen et al., 2005), apples (Wang et al., 2006) and persimmons (Tiwari et al., 2008), and dry products, such as almonds (Gao et al., 2010), beans (Jiao et al., 2012), grain (Nelson, 1996), pecans (Nelson and Payne, 1882), and walnuts (Mitcham et al., 2004; Wang et al., 2007b). Lack of RF heating

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uniformity in fresh fruit often results in unacceptable product quality (Drake et al., 2005; Wang et al., 2006). But RF disinfestation treatment protocols have been developed for beans and walnuts after heating uniformity is improved with hot air surface heating, product movement on conveyors, and mixing (Wang et al., 2002, 2007a; Jiao et al., 2012). For example, treatments at 55 °C for 5 min result in complete control of fifth-instar navel orange worm in in-shell walnuts both with pilot- and industrial-scale RF systems without causing quality losses (Wang et al., 2002, 2007b). Chestnuts are different from fresh fruit and dry products since their kernel moisture contents are around 50% with different dielectric properties (Guo et al., 2011; Zhu et al., 2012). It is desirable to develop a RF treatment protocol for disinfesting chestnuts without affecting product quality.

The objectives of this research were (1) to compare the heating rates of chestnuts when subjected to hot air and RF heating, and determine an effective cooling method after heating, (2) to study the RF heating uniformity in chestnuts using additional hot air for surface heating, moving, and mixing, and (3) to determine moisture content, protein, fat, soluble sugar, firmness, and color of chestnuts after RF treatments and for an accelerated storage.

2. Materials and methods

2.1. Materials

In-shell chestnuts (*Castanea mollissima*) were purchased from a local wholesale market in Yangling, Shaanxi, China. The average initial moisture content and individual weight of tested chestnuts were 51.27 ± 1.19% on wet basis and 11.71 ± 0.91 g, respectively. The chestnuts were stored with mesh bags in a refrigerator (BD/BC-297KMQ, Midea Refrigeration Division, Hefei, China) at 3 ± 1 °C. They were taken out from the refrigerator 12 h before the experiment and kept at ambient room temperature (20 ± 1 °C) for equilibration.

2.2. Hot air-assisted RF heating system

A 6 kW, 27.12 MHz free-running oscillator RF system (SO6B, Strayfield International, Wokingham, UK) was used to heat chestnuts associated with a hot air system supplied by a 6 kW electric heater (Fig. 1). Moving the top electrode (40 cm × 83 cm) was used to change the electrode gap, and thus regulate RF power. Samples between electrodes were moved on a conveyor belt during RF heating to simulate continuous processes. The 2.5 kg in-shell chestnuts were placed in a plastic container (26 cm × 18 cm × 8 cm, HF-932, Zhejiang Howfun Company, Taizhou, China) made of polypropylene with perforated side and bottom walls, which allowed hot or room air to pass through the samples for heating or cooling. The hot air speed was from 1.1 to 1.6 m/s inside the RF cavity provided through an air distribution box under the bottom electrode and measured at 2 cm above the bottom electrode by an anemometer (DT-8880, China Everbest Machinery Industry Co., Ltd., Shenzhen, China).

2.3. Electrode gap selection

Different electrode gap in the RF system results in corresponding electric current and RF power. The electrical current (I, A) was displayed on the console of the RF system, and used to estimate the output power (P, kW) of the RF system with a relationship ($P = 5 \times I - 1.5$) provided by the manufacturer (Jiao et al., 2012). To determine the appropriate electrode gap, the plastic container filled with and without 2.5 kg of chestnuts was placed on the conveyor above the bottom electrode. After the RF power was turned on without hot air heating and movement, the electrical current was recorded when the electrode gap was reduced from 15 to 11 cm with a distance interval of 0.5 cm. Tests were repeated two times. Based on the electric current values, three electrode gaps were selected for further heating rate tests.

To determine the best one from the three electrode gaps for studying RF heating uniformity and treatment protocol, the sample temperature was measured at the central position of the container using a six-channel fiber-optic temperature sensor system (HQ-FTS-D120, Heqi Technologies Inc., Xian, China) with an accuracy of ±0.5 °C. The probe was inserted into chestnut kernels through predrilled holes. The temperature of samples was recorded every 1 s, until the temperature reached 55 °C, and then the RF power was turned off. The tests were replicated 2 times. The final gap was selected based on the suitable heating rate (6–8 °C/min) of chestnuts, and the most suitable gap was used for further tests.

2.4. Comparisons of temperature profiles of chestnuts

Based on the thermal death kinetics of storage insect pests, 100% inactivation could be reached when the final temperature and holding time might achieve 52 °C and 5 min, respectively (Wells and Payne, 1980; Johnson et al., 2010). Moreover, the best drying temperature of chestnuts was 60 °C for the highest amylose content, resistant starch, and swelling index (Correia and Beirão-da-Costa, 2012). Taking into consideration the non-uniformity of RF heating, the target sample temperature of 55 °C was selected to develop the treatment protocol.

The container with 2.5 kg samples was placed on the center of the RF bottom electrode for hot air and RF heating. The sample temperature at the geometric center of the container and the air temperature in the RF cavity were recorded every 60 s by the fiber-optic temperature sensor system during heating with a forced hot air at 55 °C and RF treatments. The measurement was stopped when the sample temperature reached 55 °C for RF heating or the sample temperature increase was below 0.5 °C for 30 min for hot air heating. Each test was repeated twice.

2.5. Determining the cooling methods and time

Rapid cooling is important to avoid quality degradation and improve processing efficiency. Chestnut samples preheated for 3 h with hot air at 55 °C were used to determine appropriate cooling methods. Chestnuts with 8 cm depth and a single layer in the plastic container were selected to determine the cooling method and time when subjected to natural and forced room air cooling. The forced room air was obtained by an electric fan (FT30-10A, Guangdong Midea Environment Appliances Manufacture Co., Ltd., Zhongshan, China). The air speeds at 2 cm above the sample surface were measured by the anemometer and were about 0.2 and 3.5 m/s for the natural and forced air cooling, respectively. Sample temperatures in the central position of the container were recorded every 60 s by the fiber-optic temperature sensor system during cooling, until the sample central temperature dropped to 30 °C. Two replicates were made for each experiment. The best cooling method with the shortest cooling time was selected and used for further RF treatment protocol development.

2.6. Heating uniformity tests

The heating uniformity is an important factor to develop a successful RF treatment protocol since it influences insect mortality and product quality. The RF heating uniformity depends on different treatment conditions, such as with or without forced hot air, with or without movement of samples on the conveyor belt, and with or without mixing. To obtain a treatment protocol and evaluate effects of RF treatments on sample quality, the optimized heating uniformity should be first determined. Full