Journal of Stored Products Research 63 (2015) 75–79

Contents lists available at ScienceDirect

Journal of Stored Products Research

journal homepage: www.elsevier.com/locate/jspr

Short communication

Validation of radio frequency treatments as alternative non-chemical methods for disinfesting chestnuts

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A R T I C L E I N F O

Article history:
Received 9 July 2015
Received in revised form
13 July 2015
Accepted 14 July 2015
Available online 26 July 2015

Keywords:
Chestnut
Disinfestation
Quality
Radio frequency
Validation

A B S T R A C T

Chemical fumigation has been widely used to control insects in postharvest chestnuts but is inherent dangers when using fumigants. The purpose of this study was to validate application of radio frequency (RF) treatments for disinfesting chestnuts as an alternative to chemical fumigation. A practical process protocol was developed to control insect pests in chestnuts using a 27.12 MHz free-running oscillator RF system. Fifth-instar yellow peach moth, *Conogethes punctiferalis*, more heat tolerant than chestnut weevil, *Curculio elephas*, under three temperature and time combinations using a heating block system, was selected as the targeted insect to validate the RF treatment protocol. Mortality of fifth-instar *C. punctiferalis* increased with increasing holding time at 55 °C using RF heating and reached 100% while holding in hot air for at least 5 min. Furthermore, there was no significant quality difference in color, fat, firmness, moisture content, protein, and soluble sugar content of chestnuts observed between RF treatments and controls. RF treatment methods hold potential to scale up for industrial applications of disinfesting chestnuts.

1. Introduction

Chestnuts have higher moisture and starch contents, but lower fat and protein contents than most other nuts (Chenlo et al., 2009; Suárez et al., 2012; Vasconcelos et al., 2010). Thus, they provide a good resource for two key insects, chestnut weevil (*Curculio elephas*) and yellow peach moth (*Conogethes punctiferalis*). It is estimated that annual losses of chestnuts due to pests are about 20% of the total production during storage in China, resulting in high economic losses (Gao et al., 2011). Therefore, it is necessary to develop an effective and efficient postharvest method for disinfesting chestnuts and reducing damage to their product quality during storage (Tang et al., 2007).

Methyl bromide fumigation has been widely used to disinfest chestnuts but in accordance with the Montreal Protocol, production and application of methyl bromide will be banned in developing countries by 2015 (UNEP, 1992). Therefore, there is an increasing interest in developing a nonchemical alternative method to control postharvest insects in chestnuts. Radio frequency (RF) interacts directly with the entire volume of agricultural products, provides fast heating (Marra et al., 2009; Zhao et al., 2000), and has been mainly proposed as physical methods for disinfesting agricultural commodities, such as almonds (Gao et al., 2010), apples (Wang et al., 2006), cherries (Ikediala et al., 2002), oranges (Birla et al., 2005), pecans (Nelson and Payne, 1982), rice (Lagunas-Solar et al., 2007; Mirhoseini et al., 2009; Zhou et al., 2015), and walnuts (Wang et al., 2002b, 2007a,b). A RF treatment protocol has been developed for disinfesting chestnuts after improving RF heating uniformity using hot air surface heating, moving, and mixing (Hou et al., 2014). To be scaled up for commercial applications, it is essential to determine the treatment efficacy using infested chestnuts with the target insects and evaluate the effects of RF treatment protocols on product quality.

In validating the developed RF treatment protocol for disinfesting chestnuts, it is necessary to determine the most heat resistant insect species and life stage for the targeted insects. A heating block system has been widely used to determine the thermal death kinetics and thermotolerance of many insects, such as codling moth (Ikediala et al., 2000; Wang et al., 2002a), naval

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http://dx.doi.org/10.1016/j.jspr.2015.07.004
0022-474X/

orangeworm (Wang et al., 2005), Indianmeal moth (Johnson et al., 2003), red flour beetle (Johnson et al., 2004), and rice weevil (Yan et al., 2014). The thermal resistance results of life stages show that the latest-instar is the most heat tolerant life stage for several insects (Johnson et al., 2003, 2004; Wang et al., 2005). Hou et al. (2015) report that the fifth-instar is the most heat tolerant stage of *C. punctiferalis* and the minimum exposure time between 44 and 50 °C to achieve 100% mortality. For developing effective RF treatments, it is needed to determine the more heat resistant insect between fifth-instar *C. elephas* and *C. punctiferalis* using the same heating block system.

Many RF treatment protocols have been developed by including hot air surface heating, moving, mixing, holding, and cooling (Gao et al., 2010; Wang et al., 2014a, 2014b). High temperature and short holding time have been commonly used to develop the effective RF treatments (Tang et al., 2000). Based on the existed non-uniform heating in RF treatments, the final insect mortality could be different from that obtained by the model heating block system. Therefore, it is desirable to validate the efficacy of infested chestnuts at the target temperature of 55 °C with different holding times.

The objectives of this study were: (1) to determine the more heat tolerant pest between fifth-instar *C. punctiferalis* and *C. elephas* using the heating block system, (2) to validate the practical RF treatment protocol using the infested chestnuts with different holding times at 55 °C hot air, and (3) to evaluate the effect of the RF treatments on chestnut quality.

2. Materials and methods

2.1. Samples

Chinese chestnuts (*Castanea mollissima*) were obtained in September, 2014 from a local wholesale market in Yangling, Shaanxi, China. The moisture content and individual weight of tested chestnuts were 47.94 ± 1.93% on wet basis (w.b.) and 6.97 ± 2.35 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 and kept at ambient room temperature (20 ± 1 °C) for 12 h before experiments.

2.2. Determining the more heat tolerant pest

A heating block system (Fig. 1) was used to determine the more heat tolerant pest between *C. elephas* and *C. punctiferalis* with the fifth-instars. Heating rate, set-point temperature, and holding time of the heating block system were controlled by customized Visual Basic software and PID controllers (i/32 temperature & process controller, Omega Engineering Inc., Stamford, CT) via a solid state relay. Detailed information about the heating block system can be found elsewhere (Wang et al., 2002a). Three temperature and time combinations: 46 °C + 8 min, 48 °C + 4 min, and 50 °C + 2 min, were selected for this comparison test to achieve 60–90% mortality. The heating rate of 5 °C/min was selected to simulate the heating rate in chestnuts during RF treatments (Hou et al., 2014).

Both *C. punctiferalis* and *C. elephas* larvae were collected from the infested chestnuts and reared at the Northwest A&F University, Yangling, China. Fifty actively moving insect larvae were placed in the insect chamber of the heating block system (HBS) and closed for each test under the given three time-temperature combinations. Control tests were conducted in the unheated block chamber for 10 min. Each treatment was repeated thrice. At the end of each exposure, the insects were removed immediately and held in a glass rearing containers (6 cm diameter × 9 cm height) covered by a fine mesh cloth for air exchange, and maintained in a rearing room at 25 ± 1 °C, 70–80% RH, and a photoperiod of 16:8 (L:D) h with artificial light for 2 days before evaluation. Insects were considered dead if no movement was observed or the body color was dark. Mortality was calculated as the percentage of dead insects relative to total treated ones for each treatment.

2.3. Procedure of RF treatments

Chestnuts were infested with the fifth-instar life stage of *C. punctiferalis*, which was the more heat resistant insect than *C. elephas*. An insect was placed through a pre-drilled hole in kernel of each infested chestnut, which was sealed with insulating tape to prevent escaping of the insects. Before each treatment, the 25 infested chestnuts were randomly mixed into the un-infested chestnuts (2.5 kg) in an insulating container (26 cm × 18 cm × 8 cm, HF-932, Zhejiang Howfun Company, Taizhou, China). This represented an artificial infestation level of 7%, well within 4–8 % of the natural infestation rate in chestnuts (Debouzie et al., 1996; Wells and Payne, 1980). The container made of polypropylene with perforated side and bottom walls was heated each time to provide oxygen for insects, and allow hot or room air to pass through the samples for heating or cooling.

Since the minimum exposure time to achieve 100% mortality of the most heat tolerant stage of *C. punctiferalis* was 3 min at 50 °C (Hou et al., 2015), the final temperature (55 °C) and four different holding times (0, 1, 3, and 5 min) were selected according to the heating non-uniformity of chestnuts using RF energy (Hou et al., 2014). The infested chestnuts mixed with other un-infested samples were heated to the target temperature by a 6 kW, 27.12 MHz free-running oscillator RF system (SO6B, Strayfield International, Wokingham, U.K.) with a hot air system supplied by a 6 kW electric heater. The detailed description of the RF system could be found in Hou et al. (2014) and Zhou et al. (2015). The gap between the top and bottom electrodes was fixed at 12 cm based on the appropriate heating rate of chestnuts achieved by RF energy (Hou et al., 2014). The RF treatment protocol consisted of RF heating to 55 °C with forced hot air, moving conveyor at 9.2 m/h, twice mixing, and holding at 55 °C hot air for 4 different times, followed by forced room air cooling in single-layer samples as determined

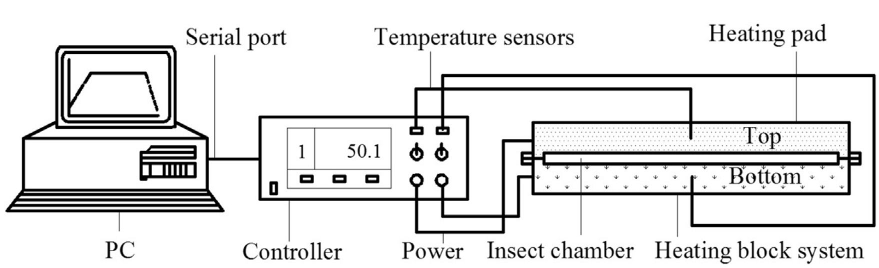

Fig. 1. Schematic view of the heating block system (Yin et al., 2006).