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Storage stability of pistachios as influenced by radio frequency treatments for postharvest disinfestations

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ABSTRACT

There has been an increased interest in developing alternative physical methods for disinfesting postharvest nuts under growing international pressures to replace chemical fumigation due to its adverse effects on human health and environment. The present research explored the possibility of using radio frequency (RF) heating as a non-chemical treatment for disinfestations of pistachios. A pilot-scale, 27 MHz, 6 kW RF unit was used to study RF heating uniformity, develop a treatment protocol, and evaluate quality attributes and storage stability in treated samples. Only 5.6 and 5.5 min were needed to raise the centre temperature of 1.8 kg in-shell and 2.0 kg shelled pistachios to reach 55 °C using RF energy, respectively, compared to about 82 and 117 min when using hot air heating at 55 °C. RF heating uniformity in both types of pistachios was improved by adding forced hot air, sample movements on the conveyor and a single mixing in the middle of the treatment time. The final average temperatures on the surface and in the interior of both types of pistachio kernels exceeded 52 °C, following a holding step at 55 °C for 2 min using hot air. This provided a conservative and 100% mortality of fifth-instar Indianmeal moth (*Plodia interpunctella* [Hübner]). RF treated samples were not significantly different from control samples in weight loss, peroxide values, fatty acid values, fatty acid composition and kernel colour. RF treatments can, therefore, potentially provide an effective and rapid protocol against stored product pests in pistachios as an alternative to chemical fumigation.

Industrial relevance: A pilot-scale 6 kW RF system with conveyor belt was used to determine the heating uniformity and quality changes of pistachios. For a combination with hot air surface heating and mixing, an effective and continuous RF disinfestation method could be developed for pistachios. The RF heating technology has been successfully demonstrated for disinfesting walnuts in California, USA. We tried to expand the industrial applications of RF heating for disinfesting pistachios, to replace the chemical fumigation. This research may provide potential industrial applications of RF treatments for disinfestations based on fast and uniform heating.

1. Introduction

Pistachio (*Pistacia vera* L.) is one of the most important tree nuts. In-shell and shelled pistachio nuts mainly dried or roasted with salt are marketed extensively all over the world, especially for the shelled or ground pistachios to be used in food industry as an ingredient of pastries, sausages, ice creams, etc. (Tsantili et al., 2010). The world production of pistachios is around 1 million metric tons in 2012, which are mainly contributed by three world producers: Iran, USA and Turkey (FAOSTAT, 2014). Pistachio nuts are important sources of nutrients, since the kernels contain about 50% of lipids and 20% of proteins, and are also a good source of vitamins and antioxidant substances (Arcan & Yemenicioğlu, 2009; Arena, Campisi, Fallico, & Maccarone, 2007; Kornsteiner, Wagner, & Elmadfa, 2006). Due to its high nutritional value and split shell, the average export prices of raw and dried pistachio nuts in 2012 had exceeded 5000 dollars per ton in the international market (FAOSTAT, 2014). Therefore, the problems related to postharvest processing of pistachio nuts are becoming major concerns of the nut industry.

Following harvest and during production, storage, marketing and exporting of pistachio nuts, insect infestation by stored-product pests, such as Indianmeal moth (*Plodia interpunctella* [Hübner]), is most often responsible for consumer returns and complaints (Johnson, Wang, & Tang, 2003). This pest reduces nut quality through direct damage and by contaminating the product with webbing, cast skins and frass, as well as creation of favourable conditions for mould growth (Johnson, Vail, Brandl, Tebbets, & Valero, 2002). Chemical fumigation using methyl bromide (MeBr) and phosphine has been a common practice for controlling insects in dried fruit and tree nuts. However, their use will be phased out in developing countries by 2015 due to its negative impact on human health and the environment (USEPA. United

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States Environmental Protection Agency, 2001). Therefore, adoption strategies of developing post-harvest technologies are of great importance to control the target insects and maintain the environment and nutritional quality of pistachios.

There are a large number of suggested potential non-chemical alternatives to fumigation, including ionizing radiation, cold storage, controlled atmospheres and thermal treatments (Hoa, Clark, Waddell, & Woolf, 2006; Jiao et al., 2013; Mexis & Kontominas, 2009; Whiting, Jamieson, Spooner, & Lay-Yee, 1999). Unfortunately each of these methods has limitations in terms of efficiency or cost that prevents it from becoming a direct replacement for fumigation. For example, cold storage and controlled atmospheres require lengthy treatment times, and consumers in Japan and the EU countries that don't accept irradiated products. Conventional thermal treatments, such as hot air or steam are relatively easy to apply, leave no chemical residues, and may offer some fungicidal activity, but an inherent difficulty in using these methods is that slow heating rates may result in long treatment times and possible damage to product quality. Thus, it is desirable to develop effective, practical, economically viable and environmentally-friendly method for disinfesting pistachio nuts.

Novel thermal treatments, such as radio frequency (RF) energy, can directly interact with commodities to generate heat volumetrically, and significantly reduce heating time or increase the heating rate so as to avoid the quality loss caused by slow or overheating in conventional thermal treatments (Marra, Zhang, & Lyng, 2009). Many studies have explored the possibility of using RF energy to disinfest produce of insect pests (Frings, 1952; Hallman & Miller, 1994; Nelson & Payne, 1982). Recently, based on the thermal death kinetics of insect pests, RF treatments have been successfully used to control codling moth (Wang et al., 2001), navel orangeworm (Gao, Tang, Wang, Powers, & Wang, 2010; Wang, Monzon, Johnson, Mitcham, & Tang, 2007b) and coffee berry borer (Pan, Jiao, Gautz, Tu, & Wang, 2012) in in-shell walnuts, almonds, and coffee beans, respectively. Available research results demonstrate that the RF technology has great potential for disinfesting pistachios.

Heating uniformity in RF-treated samples is important to achieve effective treatments that ensure insect control and provide acceptable product quality. Factors resulting in non-uniform heating during RF treatments include non-uniform electromagnetic field distribution, variations of moisture content, and thermal and dielectric properties in products (Jiao, Johnson, Tang, & Wang, 2012). Many practical methods are used to improve the uniformity of RF heating in agricultural products, such as adding forced hot air for sample surface heating, sample movement, rotation or mixing of samples during RF heating and immersing products into water for fresh fruits (Birla, Wang, Tang, & Hallman, 2004; Tiwari, Wang, Birla, & Tang, 2008; Wang, Monzon, Johnson, Mitcham, & Tang, 2007a). Similar research is desirable to determine RF heating uniformity in developing postharvest treatment protocols for disinfesting pistachio nuts.

Since pistachio kernels contain substantial quantities of triacylglycerols and polyunsaturated fatty acids, and thus may be susceptible to oxidative and hydrolytic rancidity, commercially viable RF disinfestation treatments must retain pistachio quality during storage period. Temperatures experienced by pistachios during RF treatments may influence their marketability and storage stability. After hot air heating of walnut and almond kernels, Buranasompob, Tang, Mao, and Swanson (2003) observed that the oxidation and hydrolytic rancidity of nut kernels did not increase at 60 °C for up to 10 min, which might be due to possible inactivation of the lipoxygenase (LOX) enzymes by thermal treatments. In previous studies, Mitcham et al. (2004) reported that the final kernel temperatures around 75 °C for a short time did not alter walnut quality after RF treatments. Therefore, it's important to determine the quality of RF treated pistachio nuts during storage period under the improved heating uniformity.

The objectives of this study were (1) to investigate heating rates in in-shell and shelled pistachios when subjected to hot air and RF heating and develop an effective cooling method after heating, (2) to study the RF heating uniformity in pistachios using additional hot air surface heating, moving and mixing, (3) confirm the efficacy of the developed treatment protocol with infested pistachio nuts, and (4) to evaluate the effect of RF disinfestations on the storage stability of pistachios during accelerated shelf life tests.

2. Materials and methods

2.1. Materials

Raw and dried in-shell pistachios (*P. vera* L. Kerman variety) were purchased from Paramount Farming Company (Lost Hills, CA, USA). The average split ratio and moisture content of nuts were 85 ± 5% and 4.85 ± 0.28% wet basis (w.b.), respectively. They were cleaned manually to remove all foreign matters and broken or immature nuts. Whole kernels (shelled) were separated manually from cracked nuts. Then two types of pistachio samples were sealed into polyethylene bags at 4 ± 1 °C until testing. Before each test, samples were placed in an incubator (BSC-150, Boxun Industry & Commerce Co., Ltd., Shanghai, China) for 12 h at 25 ± 0.5 °C for equilibrium.

2.2. RF heating system and procedure

RF heating of pistachios was carried out using a 6 kW, 27.12 MHz pilot-scale RF system (SO6B, Strayfield International, Wokingham, U.K.) with a hot air system (6 kW) and a conveyor belt (Fig. 1). Moving the top electrode (40 cm × 83 cm) was used to change the electrode gap, thus regulating the RF power. A conveyor belt moved samples between electrodes started from in-feed side to out-feed side of the RF system to simulate continuous processes. The hot air speed was 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).

Pistachio samples were put in a plastic container (27 cm × 18 cm × 8 cm) with perforated side and bottom walls and then placed on the centre of the bottom electrode for RF or hot air heating. Based on the thermal death kinetics of Indianmeal moth, complete kill could be reached when the final temperature and holding time achieve 52 °C and 1 min, respectively (Johnson et al., 2003). Taking into consideration the non-uniformity of RF heating, the target sample temperature of 55 °C was used to develop the treatment protocol.

2.3. Determination of the electrode gap and cooling method

Different electrode gaps in the RF system result in corresponding RF power and heating rate. To determine the suitable gap for the desired heating rate 4–6 °C/min, about 1.8 kg of in-shell and 2.0 kg of shelled pistachios with 7 cm sample depth in the container described above were placed on the centre of the bottom electrode and subjected to RF heating without belt movement and hot air heating. The range of the electrode gap was selected from 10.5 to 12.0 cm and 9.5 to 11.0 cm with a 0.5 cm interval for in-shell and shelled samples, respectively.

Pistachio samples were also heated to about 55 °C by hot air, which were used to compare the temperature profiles with RF heating and select the best cooling methods. Since rapid cooling is important to avoid quality degradation and improve throughput of the industrial-scale treatments, in-shell and shelled samples both at 7 and 4 cm depths, and additional single layer held in the container were subjected to ambient natural and forced air for cooling tests. The forced air cooling was obtained using an electric fan. The air speeds at 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.

During the tests described above, the kernel temperature of a pistachio (in-shell and shelled) in the centre of the samples was measured using a fibre-optic temperature sensor system (HQ-FTS-D120, Heqi