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Drying and decontamination of raw pistachios with sequential infrared drying, tempering and hot air drying

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ABSTRACT

Pistachio nuts have been associated with outbreaks of foodborne disease and the industry has been impacted by numerous product recalls due to contamination with *Salmonella enterica*. The current hot air drying of pistachios has low energy efficiency and drying rates, and also does not guarantee the microbial safety of products. In the study described herein, dehulled and water-sorted pistachios with a moisture content (MC) of 38.14% (wet basis) were dried in a sequential infrared and hot air (SIRHA) drier to <9% MC. The decontamination efficacy was assessed by inoculating pistachios with *Enterococcus faecium*, a surrogate of *Salmonella enterica* used for quality control in the almond industry. Drying with IR alone saved 105 min (34.4%) of drying time compared with hot air drying. SIRHA drying of pistachios for 2 h with infrared (IR) heat followed by tempering at a product temperature of 70 °C for 2 h and then by hot air drying shortened the drying time by 40 min (9.1%) compared with drying by hot air only. This SIRHA method also reduced the *E. faecium* cell population by 6.1-log CFU/g kernel and 5.41-log CFU/g shell of pistachios. The free fatty acid contents of SIRHA dried pistachios were on par with that of hot air dried samples. Despite significant differences in peroxide values (PV) of pistachio kernels dried with the SIRHA method compared with hot air drying at 70 °C, the PV were within the permissible limit of 5 Meq/kg for edible oils. Our findings demonstrate the efficacy of SIRHA drying in achieving simultaneous drying and decontamination of pistachios.

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1. Introduction

Pistachio kernels are a good source of fat (50–60%) and contain unsaturated fatty acids (linoleic, linolenic and oleic acids) essential to the human diet (Maskan and Karatas, 1998; Shokraii, 1977). They are consumed as a snack food and have broad use in the confectionery food industry. The drying of pistachio nuts presents a significant challenge due to the possible loss of nutrition, such as vitamin A and C, and protein, during dehydration. The quality of dried pistachio nuts depends on the quality at harvest and fast and efficient postharvest handlings, including hulling, drying and post-drying storage. During the drying process, nuts may undergo undesirable reactions that cause degradation in quality due to the development of odd colors and flavor. It is known that the major deteriorative reaction in dried foods is due to oxidation of lipids (Tavakolipour, 2011). Pistachio kernels have a high lipid and unsaturated fatty acid content, which makes them very sensitive to rancidity. About 3% of pistachio production is lost by rancidity development and fungal growth due to adverse weather conditions followed by improper drying practices.

Besides the need to preserve the chemical and sensory quality of pistachios during processing and storage, there is an increasing concern over the microbial safety of pistachio nuts due to the presence of several serotypes of *Salmonella enterica* in pistachio nuts and pistachio-containing products, which resulted in the recall of >16 million pounds of such products by the US Food and Drug Administration in 2009 (CDC, 2009a, 2009b). Surveys of pistachios produced in several countries confirmed the prevalence of *S. enterica* in pistachios at various levels (Al-Moghazy et al., 2014; Harris and Ferguson, 2013; Harris et al., 2016; Little et al., 2009, 2010) and nine recalls of pistachios due to contamination with *S. enterica* had taken place by July 15, in 2016 in the USA (FDA, 2016). Furthermore, a multistate outbreak of *Salmonella* Montevideo infections in the USA was linked to in-shell and shelled pistachios grown in California, the world second largest producer and

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exporter of pistachios after Iran (CDC, 2016). Outbreaks of salmonellosis have occurred also from contaminated almonds in the USA (CDC, 2004), Sweden (Müller et al., 2007) and Australia (NSW Food Authority, 2012), and from pine nuts in the USA (CDC, 2011a). Additionally, in 2015 alone, numerous recalls occurred in the USA due to *Salmonella* contamination of macadamia nuts, pine nuts, walnuts, hazelnuts, pecans and cashews (FDA, 2016). Furthermore, outbreaks of *E. coli* O157:H7 infections have been linked to contaminated walnuts and hazelnuts (CDC, 2011b; CFIA, 2011). Microbial contamination presents serious health hazards and related recalls cause great economic losses to the nut industry. Consequently, the emergence of nuts as an important vehicle of food-borne illness has prompted investigations into the development of novel technologies that are suitable for the decontamination of this type of low moisture food product.

In commercial postharvest processing, pistachios are washed and sorted in a water bath before air drying, resulting in significant moisture gain on the nut surface. The hulled pistachio nuts contain 40 to 50% (wet basis) of moisture and therefore, drying of pistachios shortly after hulling is vital to avoid shell staining, decay, and microbial growth, and thus, to increase shelf life (Kader and Maranto, 1985). Various approaches are used for drying pistachios depending on the scale of production. Sun drying requires 3 to 4 days depending on the temperature, and is labor intensive and unhygienic. Hot air rotary screen drying requires 5 to 10 h of drying time. During this process, the hot air temperature is maintained below 82 °C to retain the shell and meat color, and flavor. Drying at a higher temperature reduces the drying time, but increases the extent of shell opening and shell separation during subsequent handling, which is undesirable (Kader and Maranto, 1985). Therefore, drying is carried out at an air temperature that compromises between drying time and shell separation. Most pistachio processors in the USA use a two-stage process wherein nuts are dried in a column dryer to 12–13% moisture with forced hot air at 82 °C and the drying is completed more slowly (24 to 48 h) with air heated to no >49 °C (Ferguson et al., 1995). The pistachio product temperature during the first stage of drying with forced hot air at 82 °C was found to be about 70 °C. The current hot air drying practices have low energy efficiency and drying rates (requiring as many as 15–20 h), as well as high labor costs, and in the light of outbreaks and numerous recalls due to contamination of pistachios with *Salmonella*, do not guarantee microbiologically safe pistachio products. Therefore, a new decontamination strategy may take advantage of the requirement in drying of nuts to simultaneously effect sanitization.

Previous studies have shown that IR drying provided improved drying rate and quality of the dried products (Ding et al., 2015; Khir et al., 2014; Pan et al., 2008). When rice with an initial moisture content (MC) of 20.6% was heated by IR for 60 s, 1.7% MC was removed during the heating period, and an additional 1.4% MC was removed after tempering and natural cooling. The IR-dried rice gave 1.9% points higher head rice yield than a control sample dried with ambient air; the IR heating and tempering treatment also completely killed the insects in the rice (Pan et al., 2008). Similarly, IR heating of rough rice to a temperature of 60 °C for less than a minute followed by natural cooling resulted in 3.37% moisture removal (Khir et al., 2014). Pre-drying of walnuts with IR for 240 s resulted in up to 7% moisture reduction for high moisture walnuts (Atungulu et al., 2013). We previously reported that IR is also an efficacious treatment for the microbial decontamination of nuts (Bingol et al., 2011; Brandl et al., 2008; Pan et al., 2012; Yang et al., 2010). IR pre-heating followed by tempering resulted in over 5.0-log reduction of *S. enterica serovar* Enteritidis PT 30 cell populations on raw almonds (Brandl et al., 2008). In a scale-up study, IR followed by holding or tempering of almonds at 80 °C for 22 min provided >4-log reduction in the cell population of the *S. enterica* surrogate, *Enterococcus faecium* (formerly *Pediococcus* spp.) (Bingol et al., 2011). We describe herein, the development of a technology based on sequential IR and hot air (SIRHA) drying to achieve faster drying and improve the microbial safety of pistachios.

2. Materials and methods

2.1. Pistachios

Pistachios of the common variety Kerman were collected immediately after hulling and water sorting from the Keenan pistachio processing plant located in Kettleman City, California. The raw pistachios were stored in a freezer at −30 °C until they were used for drying experiments and were thawed to 24 °C on open trays prior to treatment. The initial moisture content of pistachios was determined by drying 5 g of ground sample of whole pistachios (shell and kernel) in an air convection oven at 105 °C ± 1 °C for 24 h (Kiliçkan et al., 2010; Venkitasamy et al., 2014).

2.2. Bacterial strain, culture conditions and inoculation onto nuts

To determine the efficacy of decontamination with SIRHA-based treatments, pistachio samples were inoculated with *Enterococcus faecium* NRRL B-2354 (formerly *Pediococcus* spp), a surrogate used for microbial quality testing (Borowski et al., 2009; Dodier, 2015), which has been accepted by the Almond Board of California (2014), and considered as safe for thermal process validation, based on genome sequencing (Kopit et al., 2014). *E. faecium* has been used for modeling bacterial inactivation in various dried foods (Rachon et al., 2016). A spontaneous rifampin-resistant mutant of this strain was isolated on tryptic soy agar (TSA) containing 100 μg/ml rifampin and was used for inoculation of pistachios in order to select against the numerous naturally occurring bacterial species present on the nuts, which interfere with bacterial plate counts. The resulting strain, *E. faecium* strain MB1051, was cultured and inoculated onto pistachios with the standard procedure described by (Danyluk et al., 2005). Briefly, the cells were grown on TSA for 2 days at 28 °C and re-suspended in tryptone buffer at an approximate concentration of 10^{10} CFU/ml. Twenty-five milliliters of the suspension was added to 400 g of raw pistachios in their shell in a bag, and the suspension and nuts were mixed by shaking. The inoculated pistachios were allowed to dry for 24 h at 28 °C and stored at 10 °C until used for treatments. Moisture content of pistachios inoculated with *E. faecium* was measured and determined to be 39.1 ± 1.2%. The moisture content of pistachios inoculated with *E. faecium* after drying using hot air and SIRHA drying methods was determined to be <9%.

2.3. Recovery of bacteria from the nuts and quantification of population sizes

After each treatment, the population size of *E. faecium* on pistachios was determined on three replicate samples of ten pistachios obtained by picking nuts at random from each of the three 20 nut-replicate samples that were used in each treatment. The pistachios were separated into shells and kernels carefully without contaminating the kernels with the shell-bound bacteria through handling. The ten pistachio kernels and shells were placed separately in 20 ml potassium phosphate buffer (10 mM, pH 7.0) in a stomacher bag containing a filter membrane (Sterile Two-Chamber Filter Bag, Labplas Inc., Ste-Julie, Canada). The samples were processed in a Pulsifier (PUL 100, Microgen Bioproducts Ltd., Surrey, UK) at the highest power for 2 min to dislodge the bacterial cells, according to the procedure described by Yang et al. (2010). The resulting suspension was dilution plated onto TSA containing rifampin at 100 μg/ml, and cycloheximide at 100 μg/ml to prevent fungal growth on the plates. The plates were incubated overnight at 37 °C and the colonies were counted for measurement of bacterial population sizes. The initial population sizes of *E. faecium* on the pistachio shells and kernels were measured prior to each treatment (control samples) and determined to be generally about 5.5×10^7 and 2×10^7 CFU/g, respectively. Average population sizes were computed from the triplicate samples.