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Research Paper

Performance of controlled atmosphere/heating block systems for assessing insect thermotolerance

Wei Li [a], Long Chen [a], Kun Wang [a], Judy A. Johnson [b], Shaojin Wang [a,c,*]

[a] College of Mechanical and Electronic Engineering, Northwest A&F University, Yangling, Shaanxi 712100, China
[b] USDA-ARS San Joaquin Valley Agricultural Sciences Center, 9611 S. Riverbend Avenue, Parlier, CA 93648, USA
[c] Department of Biological Systems Engineering, Washington State University, Pullman, WA 99164-6120, USA

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Heated controlled atmosphere (CA) treatments have potential as alternatives to chemical fumigation for disinfesting postharvest fresh and stored products. To determine accurately the minimal thermal requirements to kill target insects over a wide range of temperatures and CA conditions, it is desirable to develop a model system to assess quickly the target insect thermotolerance. This study evaluated the gas tightness of the new controlled atmosphere/heating block system (CA–HBS) and the stability of gas concentrations, and determined temperature variations in the treatment chamber with and without added gas and under different gas channel designs and heating rates. The results showed that the new CA–HBS had a relatively constant leakage rate and kept O_2 and CO_2 concentration variations to within ±0.067% and ±0.167% at three set points (1% O_2:15% CO_2, 2% O_2:17% CO_2, and 2% O_2:20% CO_2), resulting in relatively stable gas compositions. With the long gas channel design, temperature variations in the treatment chamber were not influenced by the addition of gas or by heating rates. The performance of the CA–HBS indicated that this model system could be used for rapid assessment of pest thermotolerance.

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1. Introduction

Postharvest products are of ten infested by various storage pests, resulting in more than 20% losses in developing countries (Doumbia et al., 2014). Chemical fumigations with methyl bromide have been widely used to control insects in stored products. Increasing public concerns over the use of agricultural chemicals that are harmful to the environment and human health (Bulathsinghala & Shaw, 2014), have increased the need to reduce their use, and the Montreal Protocol has mandated phasing out the use and production of methyl bromide for postharvest phytosanitary purposes by 2015 in developing countries (USEPA, 2001). Therefore, it is necessary to develop an alternative non-chemical treatment for postharvest disinfestation of stored products.

Several alternative non-chemical treatments have been suggested, including low pressure (Kucerova, Kyhos, Aulicky, & Stejskal, 2013), cold storage (Nakakita & Ikenaga, 1997), irradiation (Follett et al., 2013), controlled atmosphere (CA,

* *Corresponding author*. College of Mechanical and Electronic Engineering, Northwest A&F University, Yangling, Shaanxi 712100, China. Tel.: +86 29 87092319; fax: +86 29 87091737.
E-mail address: shaojinwang@nwsuaf.edu.cn (S. Wang).
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Carvalho et al., 2012; Conyers & Bell, 2007), radio frequency (Wang, Monzon, Johnson, Mitcham, & Tang, 2007b) and microwave (Vadivambal, Jayas, & White, 2008). Low pressure, cold storage and CA require lengthy treatment times for disinfestation, which may also cause loss of product quality. Irradiation is effective for postharvest pest control in many commodities, but few dedicated irradiation facilities are available and a number of export markets (Japan, Taiwan, and the EU) severely limit or ban irradiated products (Follett & Weinert, 2012). Although radio frequency and microwave treatments may result in non-uniform heating, they show promise for disinfestation of low moisture products (Wang, Zhang, Gao, Tang, & Wang, 2014). The mechanism of CA treatments relies on interference with insect respiration and metabolism, and is highly temperature dependent (Donahaye, Navarro, Rindner, & Azrieli, 1996; Navarro, 2006). Combining rapid heating with CA could reduce the exposure times necessary for insect mortality without adversely affecting product quality (Fleurat-Lessard, 1990; Neven, Wang, & Tang, 2012; Sen, Meyvaci, Turanli, & Aksoy, 2010; Soderstrom, Brandl, & Mackey, 1996). Therefore, it is important to obtain accurate information on the minimal requirements for mortality of target insects over a wide range of temperatures and CA conditions to allow flexibility for treatment development.

Thermal response studies and efficacy tests are necessary steps to develop effective disinfestation treatment protocols, but they are time consuming and costly. A model system is needed to quickly assess the thermal response and determine the most thermotolerant life stage of target insects (Neven et al., 2012). For example, a unique experimental heating block system (HBS) has been developed for testing responses of insects to high temperatures and heating rates (Ikediala, Tang, & Wig, 2000; Johnson, Wang, & Tang, 2003; Wang, Ikediala, Tang, & Hansen, 2002; Wang, Tang, Johnson, & Hansen, 2002). The HBS is more accurate and versatile than previously reported methods for studying thermal mortality of insects. The HBS can be programmed to simulate the heating rate of the interior of products when subjected to different heating methods, such as hot air, hot water and radio frequency (RF) treatments. This method eliminates the effect of heat transfer in various hot air/water experiments on the intrinsic thermal death kinetics of insect pests. The HBS has generated highly repeatable results in ambient air for codling moth, navel orange worm, Indian meal moth, Mediterranean fruit fly, and Mexican fruit fly (Gazit, Rossler, Wang, Tang, & Lurie, 2004; Hallman, Wang, & Tang, 2005; Johnson et al., 2003; Wang, Ikediala, et al., 2002; Wang, Tang, et al., 2002). Thermal mortality data developed with the HBS have been validated using nuts or fresh fruits infested with target insect pests, including apples (Wang, Birla, Tang, & Hansen, 2006), cherries (Feng, Hansen, Biasi, Tang, & Mitcham, 2004; Hansen, Wang, & Tang, 2004), and walnuts (Mitcham et al., 2004; Wang, Monzon, Johnson, Mitcham, & Tang, 2007a, 2007b).

The use of commodity for initial dose response studies is not always practical, and often results in more variability than carefully controlled laboratory tests. Thus, the model systems are developed to quickly screen the most thermotolerant life stage of the target insects and determine the dosage required to achieve phytosanitary levels when subjected to CA and thermal treatments. For example, Donahaye et al. (1996) studied the effects of different gas concentrations on the mortality of *Tribolium castaneum* under temperature and modified atmospheres by laboratory experiments. But these previous systems were relatively slow, labour-intensive, and not amenable to treating large numbers of insects under accurate temperatures, heating rates and gas concentrations. Neven et al. (2012) modified the existing HBS to add controlled atmospheres and studied the effects of CA and heat on Oriental fruit moth mortality. The HBS has been used to test the response of storage pests to heat treatments (Johnson et al., 2003, 2004), which indicated that it can be suitable for developing an improvement system to test the response of storage pests to heated controlled atmosphere treatments. However, undetected variations in block temperatures and gas concentrations might be responsible for the observed variation in test insect mortality.

Stability of block temperatures, gas concentrations and heating rates are important performance characteristics of the new HBS, and changes to these parameters may affect test insect response (Das, Gurakan, & Bayindirli, 2006; Neven, 1998; Wang et al., 2006). In particular, stability of gas concentrations in the insect treatment chamber is an important performance characteristic for determining insect responses to CA (Chiappini, Molinari, & Cravedi, 2009; Donahaye et al., 1996; Moleyar & Narasimham, 1994). Heating rates have clear effects on insect thermal mortality (Neven, 1998; Thomas & Shellie, 2000; Yan, Huang, Zhu, Johnson, & Wang, 2014). The HBS can be used to simulate the slow heating rates in bulk stored products in conventional thermal treatments and fast heating rates in RF heating treatments (Wang et al., 2007a, 2007b). With the HBS, Wang, Ikediala, et al. (2002) studied the effect of heating rates on thermal death kinetics for codling moth in ambient air, and reported that the lethal time (LT) accumulated during the ramp period varied with the heating rate. As temperature and flow rate of added gases may affect heating rates and temperature uniformity, these parameters need to be determined before beginning insect thermal death kinetic tests.

The general objective of this research was to avoid the confounding effects of heat transfer for different sized products and provide basic heat treatment parameters that may be used in developing pest control treatments for a variety of treatment methods. Specific objectives were to 1) develop a model HBS suitable for studying pest thermotolerance under heated controlled atmosphere treatments, 2) determine the gas tightness of the modified CA–HBS, 3) evaluate the stability of target gas concentrations, 4) determine the block temperatures as influenced by gas channel designs and block heating rates in the CA conditions, and 5) apply the CA–HBS to assess the insect mortality.

2. Materials and methods

2.1. Description of controlled atmosphere/heating block systems

The controlled atmosphere/heating block system (CA–HBS) was composed of three gas cylinders, a gas mixing flask, an

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