Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/issn/15375110

Research Paper

Improving the effectiveness of heat treatment for insect pest control in flour mills by thermal simulations

Simona M.C. Porto [a], *Francesca Valenti* [a], *Salvatore Bella* [c], *Agatino Russo* [b], *Giovanni Cascone* [a], *Claudia Arcidiacono* [a,*]

[a] *University of Catania, Department of Agriculture, Food and Environment (Di3A), Building and Land Engineering Section, via S. Sofia 100, 95123, Catania, Italy*

[b] *University of Catania, Department of Agriculture, Food and Environment (Di3A), Applied Entomology Section, via S. Sofia 100, 95123, Catania, Italy*

[c] *(CREA-OFA) Consiglio per la Ricerca in Agricoltura e l'Analisi dell'Economia Agraria, Centro di Ricerca per l'Olivicoltura, la Frutticoltura e l'Agrumicoltura, Corso Savoia 190, 95024, Acireale, CT, Italy*

ARTICLE INFO

Article history:
Received 7 June 2017
Received in revised form 22 September 2017
Accepted 31 October 2017
Published online 17 November 2017

Keywords:
Thermal behaviour
Building insulating materials
Temperature distribution
Heat flux reduction
Food safety

The aim of this study was the development of a method to improve the effectiveness of heat treatment (HT) for insect pest control in flour mills by thermal analyses and temperature trend models.

Specific attention was paid to surface temperatures of thermal bridges (TBs), which represent HT weakness points because they provide refuge to insects and increase expenditure of electric power due to heat flux loss.

Air and TB surface temperatures were monitored in a flour mill during execution of an HT. A first thermal analysis showed that values of indoor air temperatures near TBs were always lower than the computed temperature level that would also guarantee insect mortality on TB surfaces. Since the length of the steady-state air temperature profile was lower than that lethal to all insect vital stages, time series forecasting models based on trend analyses were used to simulate the suitable HT duration. The results highlighted that HT should be increased by 9 h to achieve an air temperature above 45 °C. Finally, to obtain TB surface temperatures lethal to insects, simulations were performed of building interventions capable of reducing sensible heat flux loss through the TBs by using insulating materials.

The method described in this paper could help operators define a more suitable HT length and support flour mill owners in decision-making when building interventions to improve heat capacity of the mill envelope should be considered to reduce the power consumption of HT.

* *Corresponding author*. Fax. +0039 0957147600/5.
E-mail address: carcidi@unict.it (C. Arcidiacono).

https://doi.org/10.1016/j.biosystemseng.2017.10.015

1. Introduction

In the past, the fumigation with methyl bromide has been widely used for disinfestation of grain storage and flour mill processing rooms. After the Montreal Protocol, fumigation has been banned due to excessive insecticide residues causing health hazards and destructive effect on the ozone layer (Birla, Wang, Tang, & Tiwari, 2008). Researchers and operators in the flour milling sector have investigated applications of integrated pest management and techniques alternative to methyl bromide for insect pest control in flour milling factories, such as heat treatment (Ghaly & Taylor, 1982; Porto, Valenti, Cascone, & Arcidiacono, 2015), radio frequency irradiation (Garbati Pegna et al., 2017; Yu, Shrestha, & Baik, 2016b, 2016a), microwave treatment (Jian, Jayas, White, Fields, & Howe, 2015) and cold storage (Ye, Song, Liang, Zheng, & Lin, 2012).

Heat treatment (HT) is an environmentally-friendly method to obtain effective insect pest control inside agro-industrial buildings, especially those related to the milling industry (Akdoğan, Casada, Dowdy, & Subramanyam, 2005; Hagstrum, Reed, & Kenkel, 1999; Hulasare, Subramanyam, Fields, & Abdelghany, 2010; Tilley, Casada, & Arthur, 2007). Flour mill products constitute an ideal substrate for the growth of various species of pests, such as arthropods, rodents and microorganisms, which lead to quality reduction of these products and other ones derived after further processing (e.g., bakery products, pasta, and bread).

The HT is generally carried out by increasing the inside air temperature of the mills up to levels able to eliminate all the insect vital stages (e.g., eggs, larvae, adults). Generally, the immature stages of insects are more tolerant to high temperatures than adults (Beckett, Morton, & Darby, 1998; Evans, 1981; Lewthwaite et al., 1998; Mahroof, Zhu, & Subramanyam, 2005; Suma, Amante, Bella, Pergola, & Russo, 2014). The air temperatures required to kill many species of stored-product insects have been reported in the literature (Dowdy & Fields, 2002; Fields, 1992; Mahroof, Subramanyam, & Eustace, 2003; Roesli, Subramanyam, Fairchild, & Behnke, 2003; Suma, La Pergola, Bella, & Russo, 2014).

During the HT, the food-processing environment, or a portion of it, is heated to reach air temperatures of 50–60 °C, which are maintained for about 24–36 h (Dowdy, 1999; Dowdy & Fields, 2002; Fields, 1992; Roesli et al., 2003; Wright, Sinclair, & Annis, 2001) by using fan heaters fed by gas, electricity or steam.

The target air temperature for an effective disinfestation should be at least 50 °C (Imholte & Imholte-Tauscher, 1999; Roesli et al., 2003; Wright et al., 2001). In this regard, pilot studies carried out in Canada and Europe have demonstrated that the lethal air temperature was between 40 °C and 55 °C on average. The available data shows that most species of insects do not survive for more than 24 h at 40 °C, 12 h at 45 °C, 5 min at 50 °C, and only 1 min at 55 °C (Brijwani et al., 2012).

The technique is not effective when some areas of the building do not reach the lethal microclimatic conditions for insects (Porto et al., 2015). Therefore, it is necessary to study the thermal regimes that develop in the food-processing environment subject to the HT in order to improve its effectiveness. These thermal regimes depend on many factors, some of which are determined by the interaction between the building and the surrounding environment, e.g., the building orientation, the wind intensity and direction at the site, and the thermal characteristics of the materials used for mill construction (Porto et al., 2015). Furthermore, in the different functional areas of the food-processing environment an uneven temperature distribution often establishes due to the geometry of the building, its construction materials and components as well as the position of equipment that can modify the heat fluxes (Campolo et al., 2013; Mahroof, 2007; Strano & Tomaselli, 2013; Subramanyam, Mahroof, & Brijwani, 2011). Therefore, some areas of the mill may reach either less than or excessively above the temperature level that is lethal for insects (Dowdy, 1999). For this reason, during the HT, operators make use of fan heaters, and even additional fans and tubes, to allow for a more uniform air and surface temperature distribution (Mahroof et al., 2003).

Based on these premises, the present study aimed at developing a method that could contribute to improve the thermal performance of flour mills during HT. Firstly, the thermal behaviour of a flourmill located in south Italy during an HT, which followed a protocol commonly established by operators in terms of duration, number and position of the fan heaters, was analysed to find out any weaknesses in treatment performance. On this basis, statistical and thermal simulations were performed to simulate the adoption of procedures and building interventions able to increase effectiveness of the HT for pest control in the flour mill.

Since the flourmill considered in this study is representative of the milling industry of South Italy in terms of the building materials and techniques used as well as the insect pest species generally found in this kind of agro-industrial building, the results of this research could be adopted for the improvement of the effectiveness of pest control in other mills of the area.

2. Materials and methods

2.1. *The building characteristics of the flourmill considered in this study*

Flour mills are built according to the standard layout used by the major construction companies. Their surface areas and volume geometry, as well as functional areas, are specific and differ from those of other agro-industrial buildings. A grain processing plant for flours and sub-products production is composed of a central multi-storey building, the flour milling plant, and other complementary structures such as silos, warehouses, and service rooms connected laterally to the central building. The height of the flour milling plant depends on production capacity and is characterised by wide volumes linked at different levels and machinery connected at the different floors by vertical ducts which carry semi-finished goods from lower floors to the higher ones and vice versa, following the production process.

The flour mill considered in this study (Fig. 1) is a five-storey building that was built in the province of Syracuse (Sicily, Italy) in the 70s and 80s. Direct surveys of the flour mill under study provided detailed information on the characteristics of the building and the relationships with the production processes.