



Review

A review of diapause and tolerance to extreme temperatures in dermestids (Coleoptera)

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ABSTRACT

Numerous species in Family Dermestidae (Coleoptera) are important economic pests of stored goods of animal and vegetal origin, and museum specimens. Reliance on chemical methods for control has led to the development of pesticide resistance and contamination of treated products with insecticide residues. To assess its practicality as an alternate method of control, we review the literature on the tolerance of dermestids to extreme hot and cold temperatures. The information for dermestid beetles on temperature tolerance is fragmentary, experimental methods are not standardized across studies, and most studies do not consider the role of acclimation and diapause. Difficulties in determining the diapause status of dermestid larvae may explain the lack of studies. The few studies that do examine these factors show that they can greatly increase tolerance to cold temperatures. The use of extreme temperatures will need to target the most tolerant life stage, which for dermestids at cold temperatures will potentially be the cold-acclimated individuals in diapause. The development of effective protocols will be facilitated by studies that clearly and completely describe experimental and statistical methods, consider factors (life-stage, acclimation, diapause) that increase tolerance to extreme temperatures, and assess the mortality at various temperatures to develop mathematical models.

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1. Introduction

Dermestid beetles (Coleoptera: Dermestidae) comprise a diverse group of more than 1200 described species in 45 genera. Most species are xerophilous necrophages; i.e., they develop on the desiccated tissues and hairs of dead animals (Háva and Nardi, 2004; Kiselyova and McHugh, 2006; Zhantiev, 2009) (Table 1). Necrophagus species (e.g., *Dermestes* spp.) feed in animal carcasses and on dead insects (Kingsolver, 2002; Zhantiev, 2009). Nidicolous species (e.g., *Anthrenus* spp.) occur on mammals and in bird nests, where they feed on hair or feathers (Peacock, 1992; Háva, 2004; Zhantiev, 2009). A small number of species are predators and feed on wasp and bee larvae, and on spider eggs (Zhantiev, 2009). Feeding on plants is atypical for the family, but their tolerance to low humidity allows some dermestids (mainly *Trogoderma* spp. and *Attagenus* spp.) to develop solely on dried cereal products (Hinton, 1945; Kiselyova and McHugh, 2006; Zhantiev, 2009).

A number of dermestids are of key economic importance. Some genera (*Trogoderma*, *Attagenus*) are pests of stored grains and stored grain products (Hinton, 1945; OEPP/EPPO, 2013). Other genera (*Attagenus* spp., *Anthrenus* spp.) are common in museums, where they damage preserved insect, bird, and mammal specimens, or items that contain plant or animal materials (Pinniger, 1991; Veer et al., 1991; Linnie, 1994). Species of *Anthrenus*, *Anthrenocerus* and *Dermestes* develop in products that contain wool, cotton, linen, synthetic fibres, and silk (Bennet et al., 1988; OEPP/EPPO, 2013). Species of *Attagenus* and *Dermestes* consume silkworm cocoons and prey on different life stages of silkworms (Kumar et al., 1988; Veer et al., 1996). About 28 species of *Dermestes* infest stored silkworm cocoons and *Dermestes maculatus* is a reported vector of the microsporidian *Nosema bombycis* Nageli, which is the causative agent of pébrine disease in silkworms (Veer et al., 1996). Dermestids also infest the packaging and containers used to ship stored products which, in combination with international commerce, have contributed to the cosmopolitan distribution of many dermestid species (Willey and Wayman, 1979; Turner, 1986).

Given their economic importance, there is a large body of research describing measures to control dermestid infestations. Control, however, is complicated by the ability of some dermestids to undergo diapause. This ability is uncommon among stored-product insects and increases the tolerance of dermestids to extreme climatic conditions and insecticides (Bell, 1994).

Control primarily has relied on fumigants and contact insecticides. Fumigants that have been used to control dermestids include methyl bromide (Lindgren and Vincent, 1959; Linnie, 1994; Fields and White, 2002; MBTOC, 2010), phosphine (Vincent and Lindgren, 1972; Bell et al., 1984; Udeaan, 1990; Linnie, 1994; Bell and Wilson, 1995; Farooq et al., 2000; Ahmedani et al., 2007), naphthalene (Linnie, 1994), p-dichlorobenzene (Linnie, 1994), and sulfuryl fluoride (Su and Scheffrahn, 1990; Rajendran et al., 2008; Sriranjini and Rajendran, 2008). Contact insecticides used to control dermestids include malathion (Lindgren and Vincent, 1959; Singh and Yadav, 1994; Khosla et al., 2005), pyrethrins (Linnie, 1994), and chlorpyrifos (Singh and Yadav, 1994; Khosla et al., 2005; Eliopoulos, 2013). Use of fumigants and contact insecticides promote the development of resistance, introduce residues into the environment, and can be detrimental to the consumer's health (Cao et al., 2002; Rajendran, 2002; Rajendran and Parveen, 2005). Methyl bromide is an ozone-depleting substance. In accordance

with the Montreal Protocol, its use has been generally banned on a global basis with some exemptions (MBTOC, 2010) such as quarantine. Phosphine is less effective than methyl bromide and some dermestids (e.g., *Trogoderma granarium*) already have evolved phosphine resistance (Vincent and Lindgren, 1972; Bell et al., 1984; Rajendran, 2002). These issues have led to examination of non-chemical methods of control, varying with the nature of the infested product (Rajendran and Parveen, 2005). Alternative methods include the use of controlled atmospheres (CO₂-rich, O₂-poor atmospheres) (Khattoon and Heather, 1990; Reichmuth et al., 1993), vegetable oils (Traynier et al., 1994), inert dust (Nakamoto, 1989), radiation (Khattoon and Heather, 1990), and extreme temperatures (Fields and White, 2002; Wright et al., 2002; Abdelghany et al., 2015).

The use of extreme temperatures may provide the most viable alternative to chemical applications. It has been used as an insect control method in North America since the early 1900s (Dean, 1911; Mathlein, 1961; Burges and Burrell, 1964), there are no reported cases of insects developing resistance to heat or cold, there are no residues to harm consumers, and it does not require registration, as do insecticides in most jurisdictions (Fields and White, 2002; Eliopoulos et al., 2011; Fields et al., 2012). However, adoption of extreme temperatures as a treatment method has been hampered by an inability to increase or decrease temperatures economically and quickly, as well as a lack of knowledge on the combination of temperature and period of exposure that is needed to control different species of dermestids (Strang, 1992; Bergh et al., 2006). Some of the studies that report on the thermal-mortality limits for insect pests in museums are based on experience rather than on controlled experiments (Linnie, 1999). Furthermore, much of the literature on the temperature tolerance of dermestids is difficult to access and (or) not recent (Fields, 1992; Linnie, 1999).

Our objectives are three-fold, we first review the literature on the tolerance of dermestid beetles to extreme temperatures, discuss factors that influence this tolerance, and examine the potential for extreme temperatures to control dermestids in different situations; e.g., museum specimens, stored-grain products. This information will facilitate the development of standard protocols to encourage adoption of extreme temperatures for use in the control of dermestid pests.

2. Mechanisms of temperature tolerance

Temperature influences almost every aspect of insect biology. Temperature affects metabolic rates, defines limits of physiological function, determines developmental times, impacts behaviour, and ultimately influences survival of the population (Lee, 1991; Bhargava et al., 2007). For stored-product insects, optimal temperatures maximize fitness and population growth. Stored-product insects require a high minimum temperature before they can complete their development. In general, temperatures above 15 °C are needed for egg-laying and optimal temperatures range between 25 and 35 °C (Fields, 1992; Strang, 1992). Suboptimal temperatures (35–40 °C and 13–25 °C) allow completion of life cycles and reproduction, but populations merely persist rather than thrive. Lethal temperatures (above 40 °C and below 13 °C) eventually cause population extinction (Fields, 1992; Wellheiser, 1992; Bhargava et al., 2007). Different species can have slightly different temperature responses (Hadaway, 1955; Loschiavo, 1960; Coombs,

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