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A review of insect cold hardiness and its potential in stored product insect control

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ABSTRACT

In this paper, we briefly review the ability of insects and mites to survive exposures to low temperatures and discuss its characteristics. The potential implications and uses for post-harvest pest control are also addressed as a paradigm of possible expansion in pest management. Exposure to low temperatures is the crucial factor for the induction of cold hardiness. Also, the contribution of the Super Cooling Point (SCP) is discussed. Moreover, insects and mites vary remarkably in their susceptibility to low temperatures, as some show a more “stable” cold tolerance while others are more opportunistic. There are certain cases where low temperatures can be utilized in the control of stored product and quarantine insects and mites. In the literature, there are numerous published studies that illustrate this use, on the basis of non-chemical based pest management. These studies are reviewed in the present paper, illustrating the potential use of low temperatures for pest control, in an IPM-based strategy, with particular emphasis at the post-harvest stages of agricultural commodities, where abiotic conditions are often more easily controlled.

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Key message

- Physical control methods, such as application of low temperatures, appear particularly promising for potential use to disinfest either commodities or structures and facilities from stored product pests
- We review the cold hardiness capacity of pests and particularly of stored products pests and discuss the prospects for control of those pests
- Understanding the cold hardiness profile of stored product pests will be the key for an effective use of low temperatures to control stored product pests

1. Introduction

Cold hardiness is defined as the capacity of an organism to survive exposure to low temperature levels. In the current paper, we review the phenomenon of cold hardiness in insects and mites, as well as the factors that affect cold hardiness. This procedure is related with the production of specific compounds, known as cryoprotectants, which are polyols and sugars. Exposure to low temperature levels is probably the most critical factor for the induction of cold hardiness, known also as acclimation (Salt, 1961; Lee, 1991). Freeze tolerant insects are able to overcome freezing by using several mechanisms, i.e. reduction of ice formation in the cells, or delay in ice formation. Conversely, the major strategy for freeze intolerant insects is based on the avoidance of exposure to lethal temperatures. One additional strategy, known as the "supercooling" is based on the pests' ability to be cooled before spontaneous ice nucleation occurs within body fluids. The temperature at which body water spontaneously freezes is termed as the supercooling point (SCP) (Zachariassen, 1985; Johnston and Lee, 1990). SCP is affected by several factors, such as life stage, age, body size etc (Andreadis et al., 2014). During the supercooling state, although body water cools below its freezing point, no crystallization occurs. However, in many cases, death is likely to occur at temperatures that are well above the SCP (Nedvěd et al., 1998; Turnock and Fields, 2005). From a practical point of view, the use of low temperatures can be utilized with success in the case of stored product and quarantine pests, provided that there is no effect on the commodity or the equipment.

2. Cold hardiness as a state

Insects as well as mites from temperate, polar, and high-altitude environments undergo several behavioral and physiological changes in order to withstand harsh temperatures and to avoid lethal temperatures of winter. These changes include selection of favorable overwintering locations, loss of body water content, induction of diapause, cessation of feeding and evacuation of gut, enhanced ability to supercool and accumulation of low weight molecular compounds, also known as cryoprotectants (Pullin and Bale, 1989; Lee, 1991; Storey and Storey, 1991; Bale, 2002; Zachariassen and Kristiansen, 2003; Zachariassen et al., 2008; Doucet et al., 2009). The most common cryoprotectants include polyols (glycerol, sorbitol and manitol), sugars (glucose, trehalose and fructose), and amino acids (Sømme, 1982; Fields et al., 1998; Renault et al., 2006; Clark and Worland, 2008). Polyols and sugars can be derived from glycogen (Muise and Storey, 1997; Worland et al., 1998) while amino acids are derived from protein degradation or reduced protein synthesis (Renault et al., 2006). Accumulation of cryoprotectants is triggered by exposure to low temperature and/or by entering winter diapause (Storey and Storey, 1983; Pullin and Bale, 1989; Han and Bauce, 1995; Kostal and Simek, 2000; Andreadis et al., 2011). Furthermore, the synthesis of such compounds can be triggered by the loss of the body water content (Sømme, 1982; Block, 1995) as well as by environmental factors (Baust, 1982; Block, 1995). Moreover, in many winter-diapausing insects, accumulation of cryoprotectants is associated with, and plays an important role in the enhancement of cold hardiness. Cold hardiness is an attribute that is required by insects that have to survive at certain times of the year or life stages at temperatures below 0 °C (Danks, 1996; Duman, 2001).

In recent years there have been many published studies on insect and mite cold hardiness. This phenomenon includes many complex adaptations in the insect and mite life cycle and is influenced by variation in species and the diverse environments that they inhabit (Lee, 1989; Danks, 2006). Low temperature acclimation is one of the key elements that affect cold hardiness in insects and mites (Lee, 1991; Block, 1995). Acclimation for a few days at low temperatures generally improves cold hardiness (Nedved, 1995; David et al., 1997; Kostál et al., 1998; Milonas and Savopoulou-Soultani, 1999; Andreadis et al., 2005). However, there are cases where acclimation does not improve cold hardiness (Popham et al., 1991; Hemmati et al., 2014; Andreadis et al., 2016). Acclimation at 10 °C for 4 weeks of both non-diapausing and diapausing larvae of the Indian meal moth, *Plodia interpunctella* (Hübner) (Lepidoptera: Pyralidae) significantly reduced mortality at −5 or −10 °C compared to non-acclimated larvae (Fields and Timlick, 2010). Likewise, rapid cold hardening with acclimation for 2 h at 4 °C of recently-eclosed adults of five coleopteran species associated with stored grain, significantly increased the survival time at various sub-zero temperature compared to that without acclimation (Burks and Hagstrum, 1999). The ratio of the 50% survivorship time of unacclimated to that of acclimated beetles was 8.7 for *Cryptolestes ferrugineus* Ganglbauer (Coleoptera: Laemophloeidae) (Burks and Hagstrum, 1999). In many cases, cold hardiness is closely linked in time with diapause (Tzanakakis, 1959; Bell, 1994; Andreadis et al., 2005; Bale and Hayward, 2010), but it is not clear how they are related, so whether there is a relation or not is controversial (Salt, 1961; Denlinger, 1991; Hodkova and Hodek, 2004).

3. Insect cold hardiness classification

Salt (1961) first classified overwintering insects into freeze tolerant or freeze intolerant (avoidance) according to their ability to withstand ice formation in the extracellular compartment of their tissues.

3.1. Freeze tolerant

Insects and mites that are freeze tolerant use a complex strategy to withstand low temperatures of winter in relation to species that are freeze intolerant (Salt, 1961). Ice formation within the tissues of the insects and mites is at most harmful, as it causes extensive damage either from perforation of the cells or from compression and deformation (Storey, 1999). Water expands by about 8% as it freezes, potentially causing injury of the cells (Danks, 1996). However, even if ice formation does not cause direct mechanical damage to the cells, the presence of ice within the tissues leads to extensive dehydration of the cell, as the water molecules that exist inside the cell are absorbed by the growing ice crystal which consequently results in shrinkage and destruction of the cell (Lee, 1989; Block, 1995; Sømme, 1999).

Thus, insects and mites that adopt the freeze tolerant strategy to winter survival must limit ice formation to find ways to overcome all of these types of injuries by limiting ice formation in the outer