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Biology and integrated pest management of *Tyrophagus putrescentiae* (Schrank) infesting dry cured hams

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ABSTRACT

The biology and physiology of *Tyrophagus putrescentiae* (Schrank) (Sarcoptiformes: Acaridae), also known as the ham, cheese or mold mite, is reviewed along with methods that have been evaluated for managing and controlling this pest. This review was conducted because the ham mite is an important target pest of the dry cured ham industry. Methyl bromide has been historically used to control mite infestations, but is now banned or being phased out of use in most countries because it is an ozone-depleting substance. Only commercially available stockpiles and quarantine and pre-shipment methyl bromide are available for use in countries that require such action. This review compares the effectiveness and feasibility of recently investigated methods to control mite infestations on dry cured ham and to discuss integrated pest management plans for ham mites. The review also proposes methods for conducting a prevention and monitoring-based integrated pest management program that relies on definitive mitigation such as fumigation only when mite numbers exceed a critical action threshold.

Contents

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1. Introduction

Tyrophagus putrescentiae (Schrank, 1781) (Sarcoptiformes: Acaridae), referred to here as the ham mite, is a post-harvest pest of durable stored foods that has been associated with dry cured ham, grains, aged cheese, spices, mushroom, dried fruit, nuts, and other stored foods (Hughes, 1976; Rentfrow et al., 2006). *T. putrescentiae* are tiny and difficult to detect at the early stage of infestations but can grow and multiply rapidly. Under ideal conditions (25 °C and 90% relative humidity), 100 mites can reproduce and render approximately 100 g of dog food to dust in less than four weeks (Sánchez-Ramos et al., 2007). *T. putrescentiae* is one of the most difficult pests to control in the dry cured ham industry because of its morphological, ecological, physiological and behavioral characteristics (Boczek, 1991; Zhao et al., 2016a).

Severe mite infestations on whole dry cured hams results in brown dust on the surface and in the cracks and crevices as well as a putrid smell (García, 2004; Jeong et al., 2005; Zhao et al., 2016a), which results in product rejection and economic losses. Despite many years of effective use of methyl bromide fumigation to control *T. putrescentiae* in the dry cured ham industry, this pesticide is being phased out of use (UNEP, 1992). Although the United States dry-cured ham industry can use existing stocks of methyl bromide, no additional methyl bromide for protecting country hams can be produced at the current time (EPA, 2017). In response to the phase-out of methyl bromide, researchers from USDA, U.S. EPA, companies, and universities have conducted research on the efficacy of using potentially effective methyl bromide alternatives. Zhao et al. (2016a) summarized the potential alternatives that were investigated in the past, including fumigants, modified atmosphere, inert dusts, pesticides, bioactive compounds, temperatures control, and food grade coatings. Recently, more strategies to control and monitor mite populations have been investigated on dry cured hams under laboratory conditions and in ham plants (Abbar et al., 2016a, 2016b; Amoah et al., 2016, 2017a; 2017b; Zhao et al., 2016b; Campbell et al., 2017, 2018; Zhang et al., 2017, 2018; Hendrix et al., 2018).

The objectives of this review are to summarize the biological features of *T. putrescentiae*, to compare recently studied methods for controlling *T. putrescentiae* on dry cured hams, and to propose how potential alternatives to methyl bromide fumigation can be used to implement integrated mite management plans for the dry cured ham industry.

2. Dry cured ham

Dry-curing or salting of meat has been used for centuries to preserve meat prior to the widespread use of modern refrigeration (Toldrá and Aristoy, 2010). Dry cured hams are primarily produced in a distinct climate zone, called the 'ham belt,' which includes most of southern Europe, China, and the southeastern United States (Toldrá and Aristoy, 2010). The most popular hams from around the world include Spanish Iberian, French Corsican, Italian Parma, German Westphalian, Chinese Jinhua, and American country ham (Toldrá and Aristoy, 2010). American dry cured ham, also known as country ham, is the uncooked, cured, and dried product resulting from a single piece of meat from the hind leg of a hog that undergoes curing, salt equalization, ripening and drying, and which may or may not be smoked (USDA FSIS 9 CFR 319.106). Country hams in the USA are mainly produced in Virginia, Tennessee, Kentucky, North Carolina, Georgia, and Missouri (Rentfrow et al., 2012). Ham production starts from the freshly slaughtered and butchered "green" ham, which weighs approximately 9.5 kg. The ham is rubbed in a curing mixture that contains salt and a variety of other ingredients, most usually nitrate/nitrite, sugar, and seasoning. The required period for curing (2–7 °C) and salt equalization (around 12.8 °C) is 45 days or longer (USDA FSIS 9 CFR 318.10 and 319.106), which allows salt to penetrate from the surface to the central part of the ham through osmotic pressure. Curing time for the ham is approximately two days for every 0.45 kg of the green weight, which is approximately 40–42 days and is dependent on the weight of the ham (Rentfrow et al., 2012). Smoking is an optional process that follows the salt equalization step. If dry cured hams are smoked, the smoking temperature must be 32.2 °C or less to maintain enzymatic activity of the proteins that are responsible for the development of the flavor and aroma of dry cured hams (USDA-FSIS, 1995). The final step of the dry curing process is aging, which is also known as "ripening" or "summer sweat", a process that is used to develop the typical ham flavor, aroma, and texture (Rentfrow et al., 2012). Dry cured hams are suspended from racks using hooks and/or ham nets and are aged for six weeks to two years, which contributes to the intense ham flavor (Graham et al., 2012). The aging environment is variable depending on season and location. USDA requires that the internal temperature during aging should not exceed 35 °C with no temperature limit specified (USDA FSIS 9 CFR 319.106). American country-style hams are normally aged at 25–30 °C with a relative humidity (RH) of 65–75% (Marriott et al., 1992). In comparison, European dry cured hams are aged at 16–25 °C and 65–80% RH (Toldrá and Aristoy, 2010). The finished dry cured ham must have lost at least 18% of its original weight and contain at least 4% salt to be a legal product in the USA (USDA FSIS 9 CFR 319.106). On average, American dry cured ham contains 6.5% salt and has a water activity (A_w) of 0.88 (Mikel and Newman, 2003).

3. *Tyrophagus putrescentiae* as a pest of dry cured hams

Pests of dry cured hams include several species of mites (order Sarcoptiformes), cheese skipper flies (*Piophila casei*), larder beetles (*Dermestes lardarius*), red-legged ham beetles (*Necrobia rufipes*), vertebrates such as rats and mice (order Rodentia), and various common fungi (e.g., species *Fusarium* or *Penicillium*) (Zhao et al.,