

Sampling

Monitoring *Tyrophagus putrescentiae* (Acari: Acaridae) With Traps in Dry-Cured Ham Aging Rooms

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Abstract

Methyl bromide is the most effective fumigant for controlling the mold (or ham) mite, *Tyrophagus putrescentiae* (Schrank) (Acari: Acaridae), the most significant pest of dry-cured ham. However, methyl bromide is being phased out of use. Therefore, integrated pest management (IPM) methods should be developed to help control mites in dry-cured ham plants. The foundation of a successful IPM program is an effective monitoring program that provides information on pest presence and abundance over time. By using food-baited traps fabricated from disposable petri dishes and a dog food-based bait, mite activity over time and space was monitored in five dry-cured ham aging rooms from three commercial processing facilities that differed in their fumigation frequencies. Weekly sampling of the mite was conducted from June 2012 to September 2013. There were significant differences in the average weekly trap captures in all facilities, especially before and after fumigation, with the majority of mites in traps prior to fumigation. Mite numbers had a pattern of sharp decline after fumigation, followed by a steady increase until the next fumigation. Average trap captures varied due to trap location over the study period at all study sites, indicating that traps could be used to identify specific locations within an aging room where mite infestation of hams was more likely to occur. These findings can inform facility managers of mite population changes that can be used as one factor toward making pest management decisions and assessing the impact of fumigation or other pest mitigation actions.

Key words: *Tyrophagus putrescentiae*, dry-cured ham, fumigation, methyl bromide, monitoring

Tyrophagus putrescentiae (Schrank) (Acari: Acaridae) is a pest of dry-cured pork, aged cheeses, and other post-harvest products (Boczek 1991). Southern dry-cured ham is produced from the hind leg of a pig carcass. The ham is first cured by rubbing salt and other seasonings on the ham and storing under refrigeration conditions (2–4°C) for 4–6 wk to allow the salt to penetrate through the ham by osmotic pressure, which preserves the ham. After curing, hams may be smoked with hardwood such as hickory or left unsmoked. Hams are then hung on racks and aged at 24–35°C and 55–65% relative humidity (RH) for a minimum of 2 mo and sometimes up to 2 yrs (Graham et al. 2011). During aging, the loss of moisture, proteolysis, and lipolysis result in a unique flavor and taste (Toldrá et al. 1997). Long-aged hams have a more complex and intense flavor that is appreciated by some consumers (Marriott and Schilling 2004). However, hams aged for more than 5 mo are more likely to be infested with *T. putrescentiae* (Rentfrow et al. 2006), commonly known as the ham mite. *Tyrophagus putrescentiae* has been isolated from over 140 commodities (Hagstrum et al. 2013), most of which are of high protein and/or high fat content with a moisture content of 15–45%. These commodities include dried fruits, spices, dried meats, cultured cheeses (Rentfrow et al. 2008), pet food

(Thind 2005, Brazis et al. 2008), cereal-based food products, and other organic materials (Thind and Clarke 2001). This mite causes direct damage that reduces product quality and quantity and may result in product rejection (Jeong et al. 2005). *Tyrophagus putrescentiae* is sometimes considered a member of the house dust mite complex and has been reported to generate human allergic reactions (Jeong et al. 2005, Wakefield 2006). *Tyrophagus putrescentiae*'s optimal growth occurs at environmental temperatures of 23.2 ± 2.1°C and RH of 71 ± 5.6% (Adler 2004, Riudavets 2004). A mite population may double in as little as 2 to 4 d: under ideal conditions of 25°C and 90% RH, 100 mites can render about 100 g of dog food to dust in less than 4 wk (Sánchez-Ramos et al. 2007, reviewed in Edde et al. 2012).

The BT trap (Central Science Laboratory, York, United Kingdom) was the first trap designed specifically for the detection and monitoring of storage mite populations and infestations in both laboratory and field studies (Thind and Ford 2004, Wakefield 2006). The BT trap is not truly a trap but rather a food bait station. The trap is a small black disc that contains a moist food bait and is equipped with openings around the entire circumference of the base to allow access by mites. In a study conducted by Thind and Ford

(2004), 15 to 25 BT traps were used to detect and monitor storage mites in three factories that produced cereal based foods for dogs, small animals, and horses, or moist, meat-based pet food for dogs and cats. Mites included *Tyrophagus* spp., with the most predominant being *T. putrescentiae*. Although numbers were low, the study showed that the traps were effective at capturing mites, even after professional cleaning and sanitation had been carried out. In a comparative field trial study conducted by Thind (2005), the BT trap detected more mites than a food bait bag composed of a mixture of cereal, peanut, and carob or a fishmeal trap, made of a moist filter paper with fishmeal covered with a raised petri dish in four different types of premises. The premises included three factories involved in the production of cereal-based dry pet food, specialist animal feed, and traditional cheese. The fourth premise was the finished cereal section of a large transit storage warehouse. At least seven species of storage and predatory mites were detected in these locations. Wakefield and Dunn (2005) reported that under test conditions of 20°C and 65% RH, the BT trap was effective at detecting mites for at least 10 d for all three species tested: *Lepidoglyphus destructor* (Schrank), *Tyrophagus longior* (Gervais), and *Acarus siro* (L.) (all Acari: Acaridae). Individuals of these three species reached a trap at a distance of approximately 80 cm in a 24-h period. In addition to the BT trap, The PC pitfall cone trap, which is used to monitor storage insects in bulk grain, was effective at detecting mites in stored grain and oilseed (Clarke 2002). According to Dunn et al. (2005), the BT and PC traps were more effective at detecting low numbers of storage mites, including *Acarus siro*, *T. longior*, and *L. destructor*, when compared with sampling and sieving.

Fumigation with methyl bromide (MeBr, CH₃Br) has been the most effective method to control mite infestations in dry-cured ham plants. Methyl bromide fumigation may be performed one to five times per year in some dry-cured ham facilities in the United States (Rentfrow et al. 2008). However, MeBr use is being phased out of use as part of the Montreal Protocol, due to its ozone-depleting nature (Environmental Protection Agency 2014). Dry-cured ham producers in the United States will therefore need research to be conducted to identify new methods to help control mite infestations. Integrated pest management (IPM) programs need to be developed for ham mites on dry-cured ham. Detection and monitoring are two of the most critical aspects of IPM for any pest. Monitoring ham mites to estimate their population density relative to commercial action levels is essential in developing an IPM program for dry-cured ham. Many ham processing facilities do not have systematic monitoring programs in place, so infestations may go unnoticed for long periods.

The broad objective of the work described in the following text was to determine if a simple food-baited trap could be used to detect and monitor *T. putrescentiae* populations. Monitoring mite activity over time and across spaces in a given structural habitat could give insights on mite population dynamics and therefore help in developing IPM programs. A specific objective was to determine if the food-baited trap could confirm the impact of MeBr fumigations on mite populations at commercial ham processing and aging facilities.

Materials and Methods

Trap Design and Food Bait

Large numbers of BT traps were not available for purchase for this study, which motivated the development of a low-cost, easily constructed trap. The food-baited trap that was developed in our laboratory was a plastic petri dish, 100 mm in diameter × 15 mm in

height, that was spray-painted black on all outside surfaces. Eight evenly spaced holes, each of approximately 0.5 mm diameter, were made above the bottom along the side of the dish, approximately 2 mm from the bottom, to allow mites to enter the trap. A 10-g circular disc of the food bait, approximately 30 mm in diameter and 10 mm in height, was placed inside at the center of the dish bottom. The lid and bottom of the petri dish were held in place using a rubber band. Preliminary testing of the food-baited traps indicated that mites enter the traps through the entrance holes to feed, mate, and lay eggs on the diet plug. Although mites were not physically retained in the traps, and could move freely in and out of the traps, it was observed that mites would clearly aggregate at the food plug once they encountered it. Data were scored as the count of all mobile mites inside the dish at the end of a given trap deployment period. Eggs were not counted.

Food baits for traps were made prior to each weekly trap deployment in batches of approximately 600 ml with the following ingredients: 475 ml water, 160 g of dry dog food (a retail commercial product composed mainly of yellow corn, chicken by-product meal, beef, rice, and soy), 40 ml glycerol (99.9%; Fisher Scientific International, Inc.), 5 g brewer's yeast (MP Biomedicals, LLC), 10 g agar (LCN Biomedicals, Inc.), 5 g alphasel (non-nutritive bulk cellulose; LCN Biomedicals, Inc.), 5 g insect vitamin mix (MP Biomedicals, Inc.), and 5 ml of methyl-p-benzoate solution (15% methyl-p-benzoate in 95% ethanol; LCN Biomedicals, Inc.). The dog food pieces were soaked in the water to soften and then blended for approximately 90 s at the highest setting in a kitchen blender until smooth with no apparent separate food pieces. The smooth mixture was combined with glycerol in a 1,000-ml Pyrex glass beaker and then brought to a boil before adding the remaining ingredients, after which the mixture was allowed to boil for approximately 5 min more to ensure the ingredients are completely dissolved and to melt the agar. The mixture was then poured into a stainless steel rectangular pan measuring 25 by 15 by 5 cm, allowed to cool to room temperature, and covered with aluminum foil. This was then stored in the refrigerator till needed for traps, at which time the circular discs were cut from the gelled food using a 30-mm-diameter cork borer.

Ham Aging Rooms

Pest populations of *T. putrescentiae* were monitored in three commercial facilities that manufacture southern dry-cured hams. These companies are referred to as Facility A, Facility B, and Facility C, and were all located in the southeastern United States. Indoor temperature and RH of each facility were monitored and recorded from April to August 2013 using data loggers (HOBO U12-006, Onset Computer Corporation, Pocasset, MA). At least one data logger was used per facility. Outdoor temperature and RH data were obtained for the same period from weather stations located within five miles of each of the facilities. Trapping for this study was conducted between June 2012 and September 2013. The three facilities varied widely in their sizes, number of hams in aging rooms at any given time, and pest management procedures. Physical descriptions of aging rooms are as follows.

Facility A

Two aging rooms in Facility A were used for this study (Fig. 1). Although both rooms were in the same building, they were separated from each other by 180 m and several rooms. Room 1 was approximately 24 m in length, 11 m in width, and 4 m in height and contained approximately 10,000 hams when full, while Room 2 was

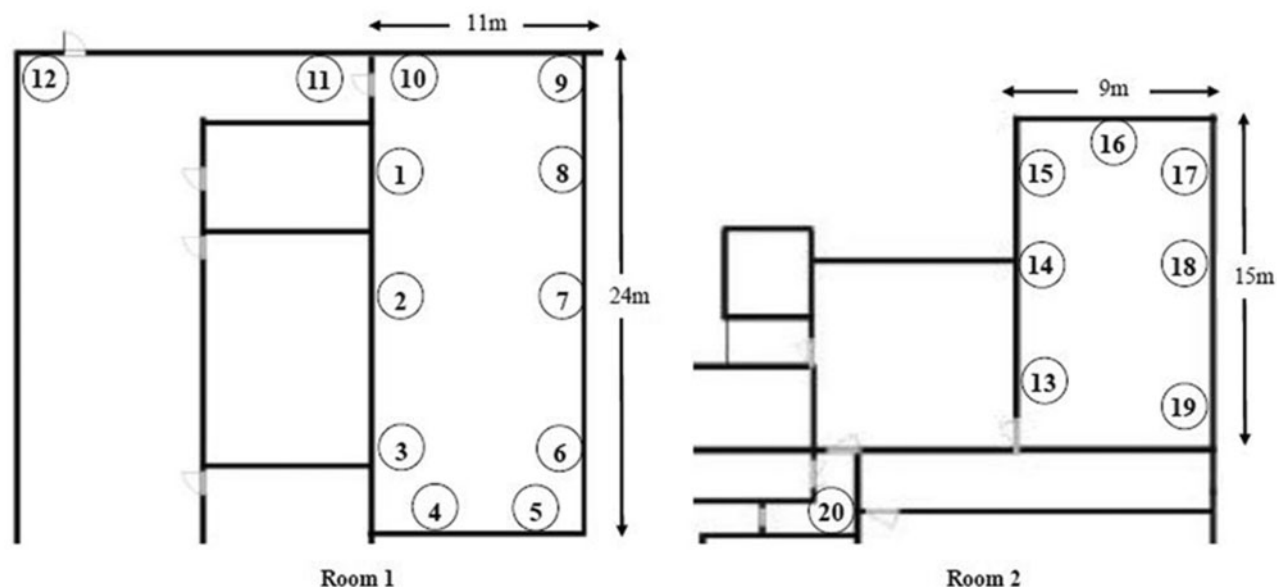


Fig. 1. Maps of dry-cured ham aging Rooms 1 and 2 in Facility A showing trap locations circled.

approximately 15 m in length, 9 m in width, and 3 m in height with approximately 7,000 hams when full. Hams were hung on wooden racks throughout the aging period. Hams in Room 1 were typically aged from 2 to 4 mo and those in Room 2 were aged up to 24 mo. Hams in both rooms were moved in and out all year-round, as needed by the company. The RH was usually kept at 50–88% for both rooms. Traps labeled 1–10 were placed in Room 1 and traps labeled 13–19 were placed in Room 2. Traps 11 and 12 were located just outside Room 1, and Trap 20 was placed in the loading dock area. Methyl bromide fumigations were performed on a given weekend for 24 h, with preparation on a Friday and ventilation on a Sunday. Fumigation with phosphine (hydrogen phosphide gas) was done in two cases over the period we studied Facility A.

Facility B

Two aging rooms, one in each of two separate buildings, were used at Facility B (Fig. 2). Room 1 was approximately 18 m in length and 5 m in width with steel racks, while Room 2 was approximately 14 m in length and 8 m in width with wooden racks. Temperature and RH were maintained at approximately $25 \pm 1^\circ\text{C}$ and 45–58%, respectively. Traps 1–9 were deployed in Room 1 and Traps 10–20 were deployed in Room 2 for the majority of the study period from week 26 to week 59. Prior to week 26, trap locations changed two different times: week 6 and week 11. Facility B was fumigated three times during the study period and these were done usually upon recommendations after trapping results. Because of the density of mites, both rooms were fumigated on Friday of week 5, but the other two fumigations in weeks 28 and 53 were carried out in Room 2 only.

Facility C

Facility C had the largest building of the three facilities studied. The aging house used for the study measured approximately 55 m in length, 14 m in width, and 10 m in height with wooden racks. There were 19 small aging rooms in the aging house, each measuring approximately 5 m in length and 5 m in width. Typically, the age of hams ranged from 1 to 6 mo. Each small room contained hams of the same age at any point in time. One trap was placed in each of the 19 small rooms and the trap labeled 20 was placed in the

common area of the aging house (Fig. 3). There was no change in trap locations throughout the study period. Four MeBr fumigation exercises were carried out in Facility C during the study period. The first was just before the start of the study and then on the Fridays of weeks 5, 12, and 52 (Fig. 10).

Trap Deployment and Evaluation

Preliminary testing of the food-baited traps indicated that 1 wk was adequate for detecting the presence of mites. Twenty traps were shipped to each of the three ham facilities on a weekly basis so that could be deployed on Mondays for a 7-d period, after which traps were collected, shipped back to our laboratory, and replaced with the new traps. After each 1-wk period of deployment, individual traps were placed in a plastic sandwich bag by facility cooperators and returned to the laboratory for evaluation. Traps were deployed no closer than 1 m and not farther than 8 m apart on the floor along the walls, near machinery or other structural edges, or underneath racks in darkened locations for Facilities A and B. Traps in Facility C were placed on exposed ledges approximately 1 m above the floor. Selected trap locations were unlikely to be disturbed by the operations of the facilities. The same trap placement locations were maintained in each facility throughout the study, unless indicated. Fumigation, including preparation, gas exposure, and ventilation, was normally from Friday to Sunday and the facilities re-opened for business on Monday. The traps were collected at the end of the week immediately preceding a fumigation.

Data Processing and Analysis

Data are presented as the mean number of mites per trap with the standard error of the means calculated for each week and for each facility. Similarly, the proportion of traps with and without mites in a given week was also calculated. When possible, the mean number of mites per week captured at each trap location within an aging room was calculated to assess variation among trap locations. We evaluated the variation in numbers of mite captures over consecutive trapping periods for each of the five aging rooms. To rule out the effect of fumigation during an assessment period, we selected trapping periods of 10 wk or more for which the first week was that just after

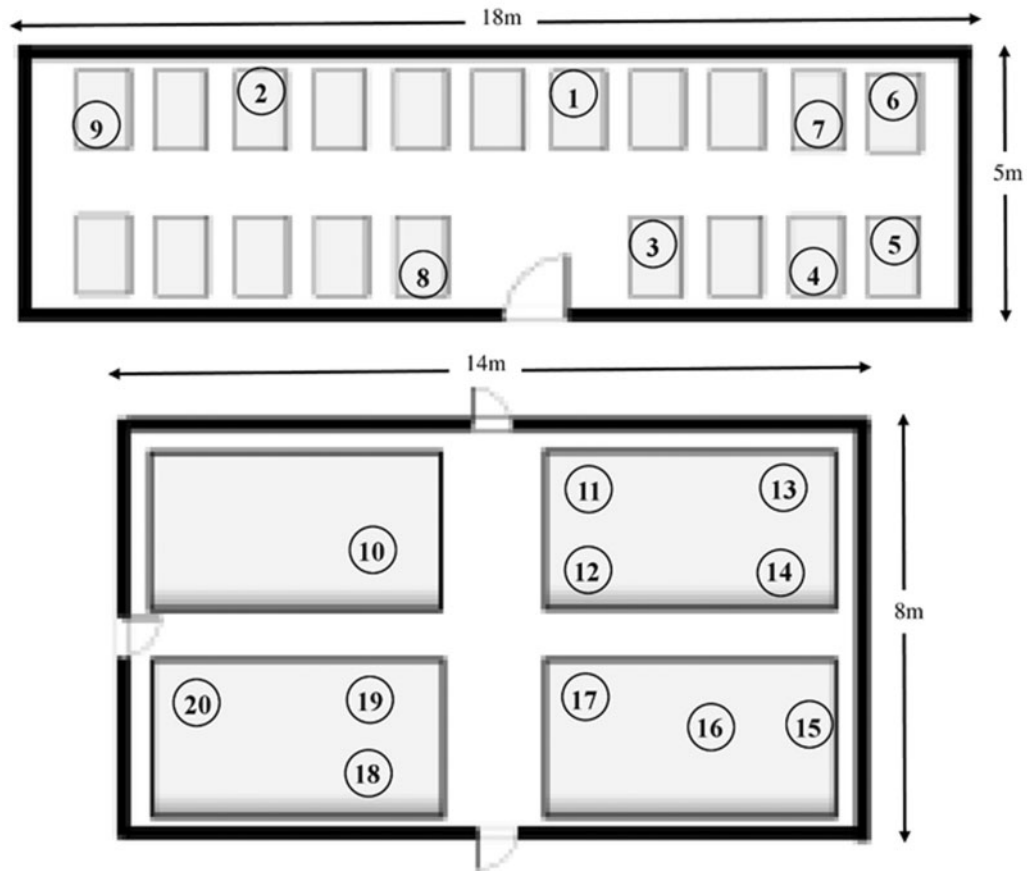


Fig. 2. Maps of dry-cured ham aging Room 1 (above) and Room 2 (below) with racks in Facility B showing trap locations.

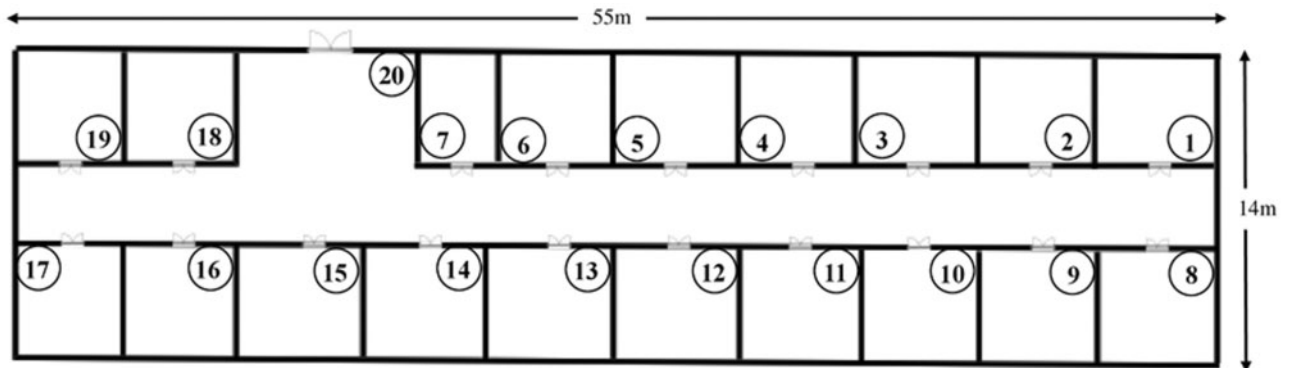


Fig. 3. Map of Facility C showing trap locations in dry-cured ham aging rooms.

a fumigation and the last week was that just before the next fumigation. Facility A was not included in this analysis due to its high frequency of fumigation not meeting our criterion of 10 wk between fumigations. Thus, one trapping period was assessed for Room 1 and two trapping periods were assessed for Room 2 in Facility B; one trapping period was used for Facility C. We calculated the correlation of mean mites per trap, the proportions of traps with mites, and mean mites per week with trapping periods in the various rooms as described using PROC CORR (SAS Institute 2002–2010). Differences in mite capture by trap location across weeks for each room were also analyzed using PROC GENMOD (SAS Institute 2010–2012), such that each trap location was an experimental unit deployed in a completely randomized design. The probability

distribution was set to a negative binomial and the link function was set to LOG transformation, as initial analysis determined that the data were not normally distributed. The means were separated on the basis of Tukey–Kramer's honestly significant difference test.

Results

Tyrophagus putrescentiae were captured in traps within all three commercial facilities throughout the study period. Results indicated that ham mites could be detected inside infested ham aging rooms, and that the weekly numbers in traps before and after fumigations reflected the changes in relative mite population sizes over time in a

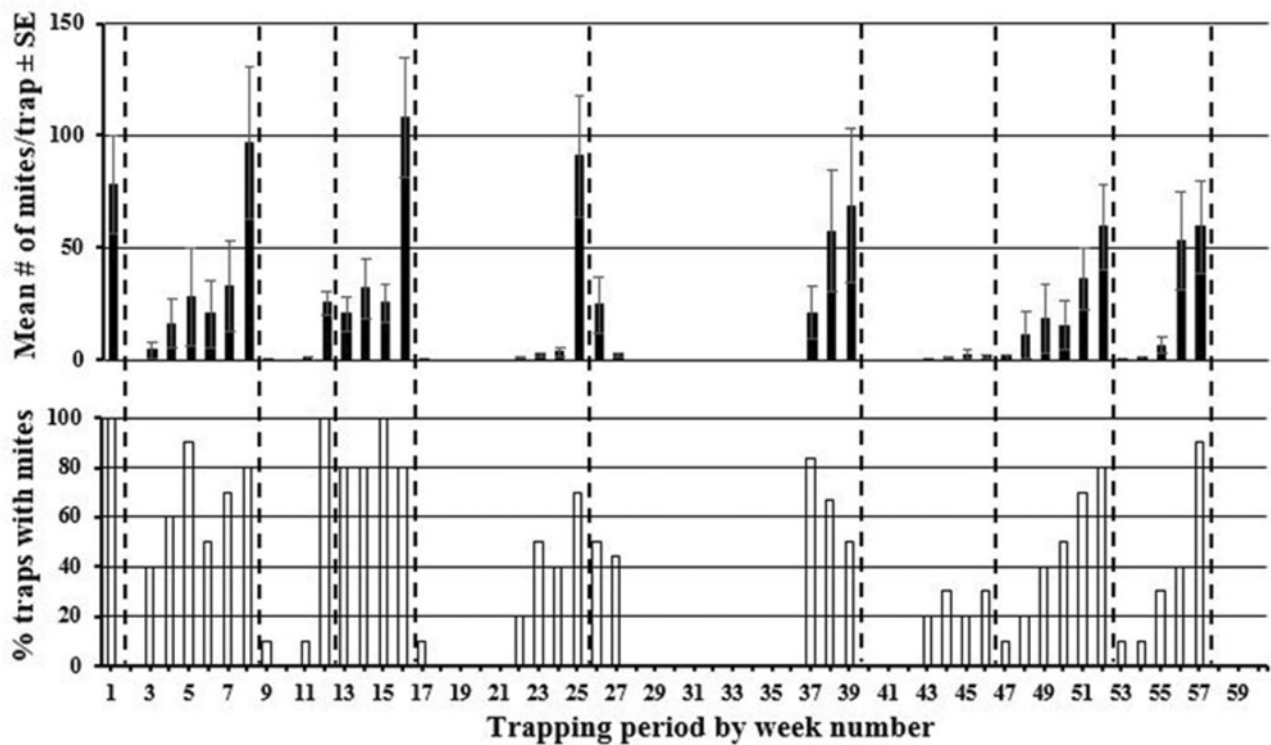


Fig. 4. Illustration of the average weekly trap captures (above) and percentage of traps with *Tyrophagus putrescentiae* from June 2012 to September 2013 for Facility A, Room 1. The dashed lines indicate fumigation dates. A cleaning exercise was carried out by the company during week 25. Traps were not deployed from weeks 28–36 and 40–42 at the request of the owner.

given aging room (Figs. 4, 5, 7, 8, and 10). A summary of indoor temperatures and RH for the three facilities is presented in Table 1. Trap capture over time showed a clear reduction in numbers of mites immediately following MeBr fumigation for nearly every case in all the aging rooms studied, but effects of cleaning on mite numbers at one facility were not clear-cut (Figs. 4, 5, 7, 8, and 10). Analyses of mite numbers relative to temperature or RH were not pursued in this study. Trapping data are presented for each facility separately in the following section.

Facility A

In Room 1 of Facility A, trap captures in the week following a given fumigation ranged from 0 to approximately 25 mites per trap. For instance, there were no mites in any trap for the first week after the fumigation, while the count after the week 25 fumigation was 24.7 ± 12.6 mites per trap (Fig. 4). Of all the fumigant applications, only the fumigation carried out during week 32 in Room 2 resulted in 0 trap counts for 4 consecutive weeks after fumigation. The percentage of traps with mite captures for both rooms during the study period ranged from 0 to 100% (Figs. 4 and 5).

Traps were ranked with respect to the mean number ($\pm$ SE) of mites caught per week by each trap. As shown in Fig. 6, the trap with the highest average capture was Trap 5 with 29.8 ± 7.7 mites per week, while Trap 14 captured the lowest number at 0.5 ± 0.3 mites per week. No trap recorded 0 mites throughout the period of study in Facility A. Also, no trap recorded mite(s) every week throughout the period of study. Traps in Room 1 caught mites in 16% (Trap 1) to 54% (Trap 10) of the trapping weeks. In Room 2, traps caught mites between 10% (Trap 14) to 37% (Trap 19) of the

time. Both Trap 14 and Trap 19 also recorded the lowest and highest mean number of mites, respectively (Fig. 6). The proportion of weeks for which a particular trap caught mites in Facility A was positively correlated with the mean mites per week at a given trap location (Table 2).

Facility B

Fumigation carried out during week 5 in July 2012 kept the trap count below two mites per trap for 20 wk in Room 1 (Fig. 7) and for 6 wk in Room 2 (Fig. 8). Fumigation of Room 2 during week 28 reduced the average trap count from 17.4 ± 4.2 to 0.4 ± 0.2 mites per trap. However, the trap counts increased dramatically to 52.8 ± 13.7 mites per trap after only 2 wk (Fig. 8). Up to about 90% of the traps deployed in Room 1 (Fig. 7) and up to 100% of the traps in Room 2 (Fig. 8) captured mites during one or more weeks. There was a positive and significant linear relationship between the trapping period from week 6 to week 60 and the mean mites per trap in Room 1. For Room 2, there was also a significant positive linear relationship for mites per trap and the trapping period of week 6 to week 28, but a very weak and nonsignificant relationship between these in the second trapping period of week 29–53 (Table 3).

Trap ranking in Facility B showed that Trap 2 recorded the highest number of mites per week at 97.7 ± 18.5 , while Trap 8 recorded the lowest number at 3.7 ± 2.2 mites per week (Fig. 9). Similar to Facility A, no trap recorded 0 mites throughout the period of study. Also, no trap recorded mite(s) for each week throughout the period of study. In Room 1, traps captured mites 18–76% of the monitoring period, for Trap 8 and Trap 5. In Room 2, mites were caught 24–79% of the monitoring period, for Trap 20 and Trap 17. Traps

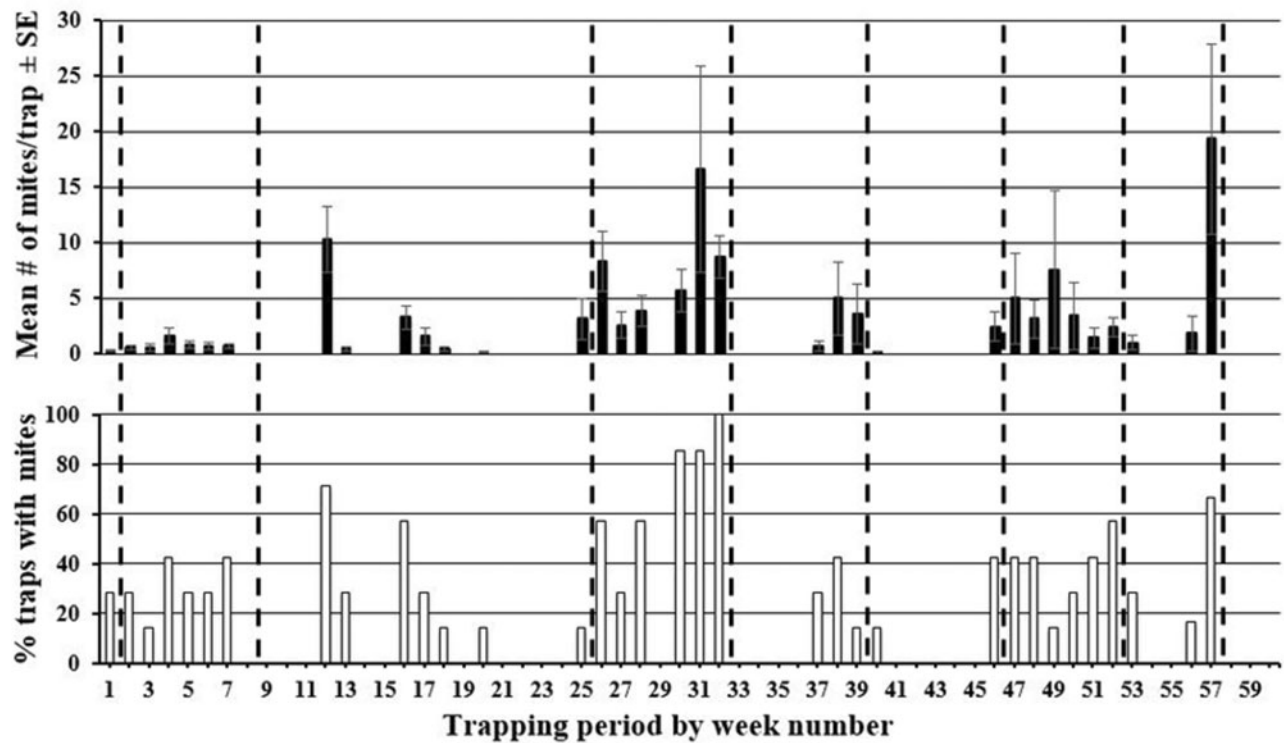


Fig. 5. Illustration of the average weekly trap captures (above) and percentage of traps with *Tyrophagus putrescentiae* from June 2012 to September 2013 for Facility A, Room 2. The dashed lines indicate fumigation dates. A cleaning exercise was carried out by the company during week 25.

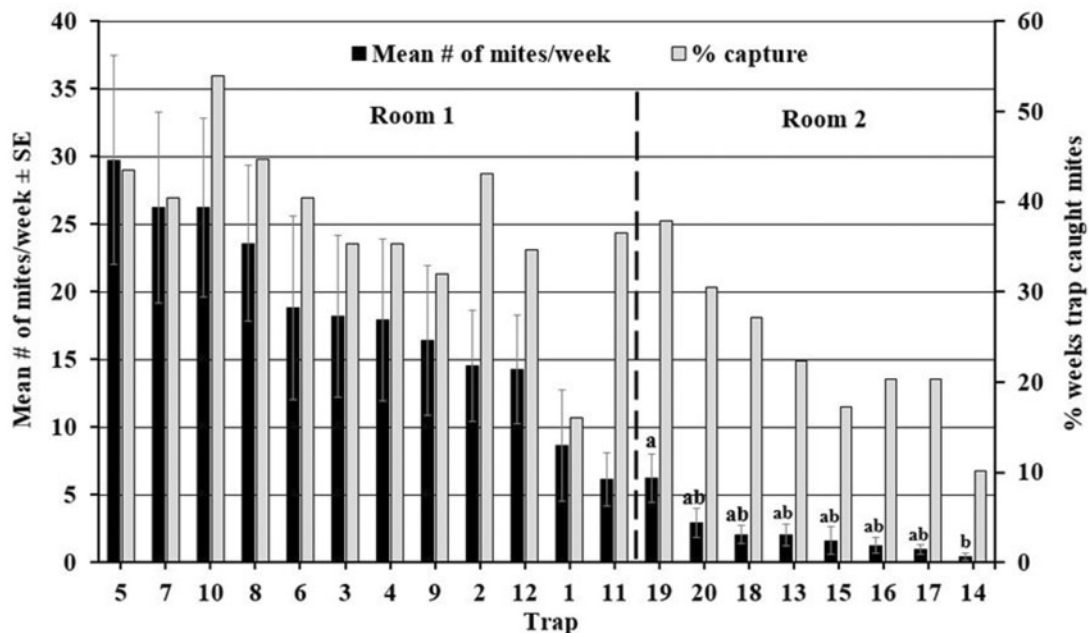


Fig. 6. Trap ranking using mean ($\pm$ SE) number of mites per week caught by each trap (left vertical axis) and percentage of weeks with mite capture in a given trap (right vertical axis) in two aging rooms (separated with dashed line) in Facility A for up to 59 wk. Means with the same letter for the Room 2 data are not significantly different ($P > 0.05$; by Tukey–Kramer's honestly significant difference test).

20 and 17 also recorded the lowest and highest number of mites, respectively, as shown in Fig. 9, and this reflects the positive and significant correlation between the proportion of weeks for which a particular trap caught mites and the mean mites per week at a given trap location for both rooms (Table 2).

Facility C

Facility C had a relatively low mite population with an average trap capture of less than one mite per trap for approximately half of the duration of the study (Fig. 10). The highest trap capture was recorded in week 59 at 18.3 ± 11.3 mites per trap. Average trap count

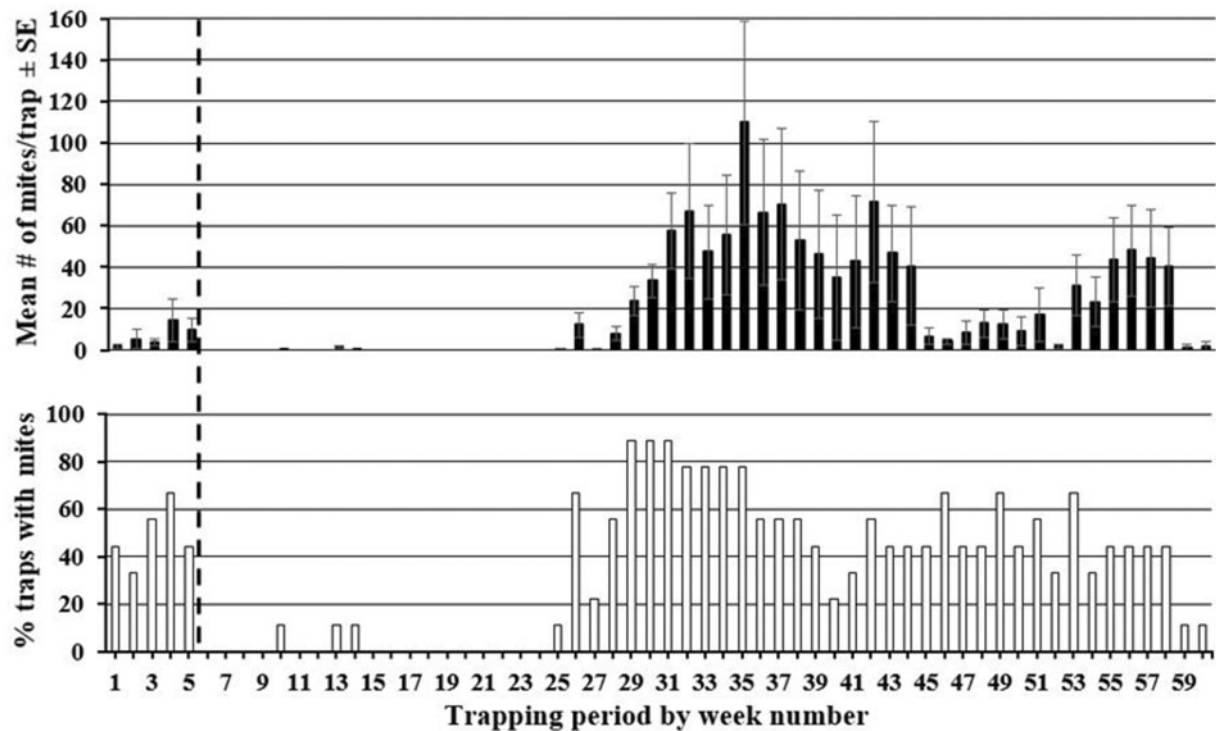


Fig. 7. Illustration of the average weekly trap captures (above) and percentage of traps with *Tyrophagus putrescentiae* from June 2012 to September 2013 for Facility B, Room 1. The dashed line indicates fumigation date.

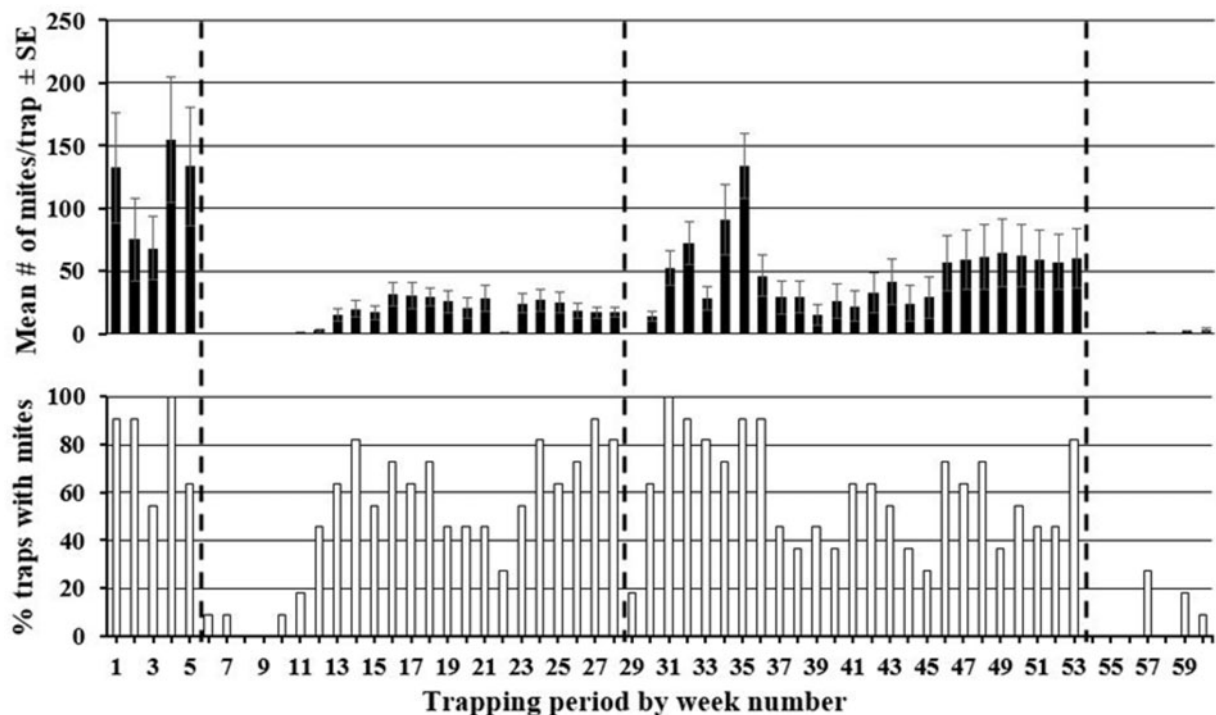


Fig. 8. Illustration of the average weekly trap captures (above) and percentage of traps with *Tyrophagus putrescentiae* from June 2012 to September 2013 for Facility B, Room 2. The dashed lines indicate fumigation dates.

just before the week 5 fumigation was 1.0 ± 0.5 , but after fumigation, there was an unexpected increase in trap capture to 3.8 ± 3.7 mites. Also, there was a slight increase in the average trap counts after the week 12 fumigation from 6.2 ± 4.6 in week 12 to 7.5 ± 6.1

in week 13. Mite numbers in traps dropped to 0 for 3 consecutive weeks after week 52 fumigation, before the average count increased to 15.0 ± 9.7 at week 56. Percent of traps with at least one mite ranged from 5% to 45%, and there were 15 wk during which no

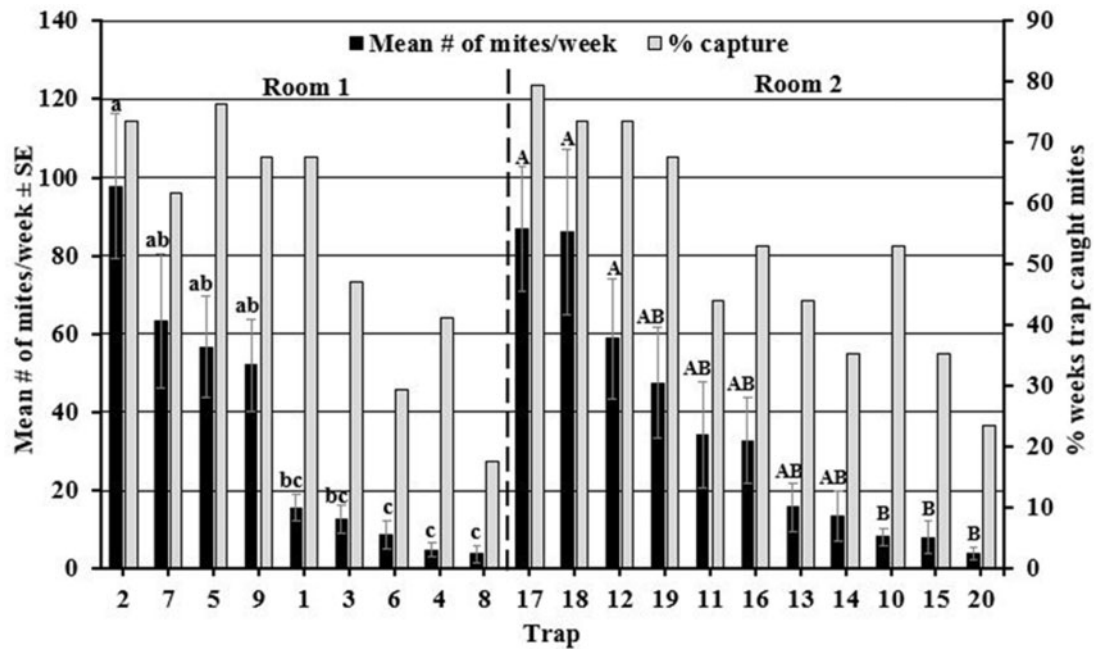


Fig. 9. Trap ranking using mean ($\pm$ SE) number of mites per week caught by each trap (left vertical axis) and percentage of weeks with mite capture in a given trap (right vertical axis) in two aging rooms (separated with dotted line) in Facility B for 34 wk from week 26 to week 59. Means with the same letter are not significantly different ($P > 0.05$; by Tukey–Kramer’s honestly significant difference test).

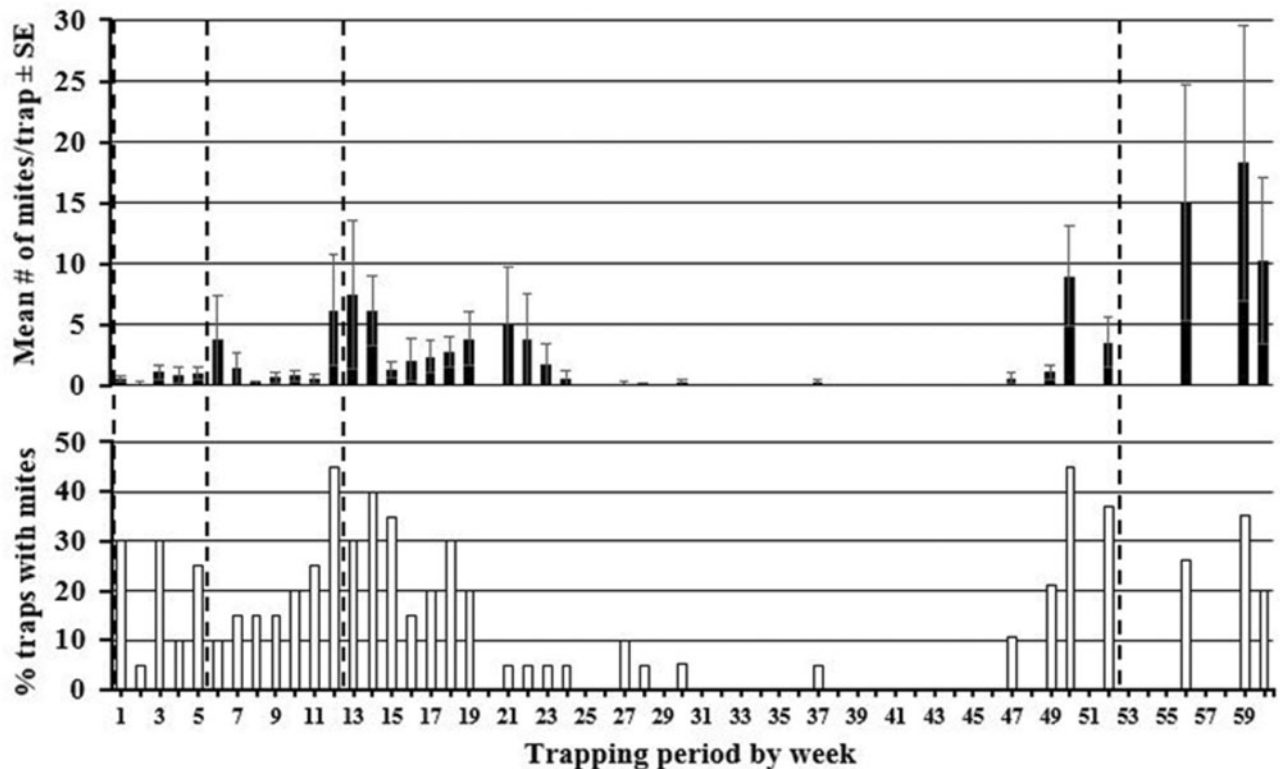


Fig. 10. Illustration of the average weekly trap captures (above) and percentage traps with *Tyrophagus putrescentiae* from June 2012 to September 2013 for Facility C. The dashed lines indicate fumigation dates.

mite was captured in any of the traps deployed (Fig. 10). There were no significant correlations between week after fumigation and either mites per trap or percentage of traps with mites ($P > 0.05$; Table 3).

When traps were ranked, the highest number of mites per week was recorded in Trap 11, with 11.0 ± 5.6 mites. Moreover, no mites were caught in Trap 15 throughout the entire study period and Trap 12 contained mites for only 30% of the monitoring period (Fig. 11).

Table 1. Average temperatures and relative humidities recorded in the three ham facilities from March to September 2013

Company	Room	Indoor temperature $\pm$ SE ($^{\circ}$ C)			Indoor RH $\pm$ SE (%)		
		Mean low ^a	Mean overall ^b	Mean high ^c	Mean low ^a	Mean overall ^b	Mean high ^c
A	1	22.9 $\pm$ 0.8	24.5 $\pm$ 0.8	26.7 $\pm$ 0.8	35.7 $\pm$ 2.2	43.0 $\pm$ 2.8	45.5 $\pm$ 2.5
A	2	18.7 $\pm$ 1.0	19.8 $\pm$ 0.9	20.7 $\pm$ 0.9	59.6 $\pm$ 1.8	62.4 $\pm$ 1.2	65.0 $\pm$ 1.1
B	1	25.2 $\pm$ 0.8	26.0 $\pm$ 0.7	26.6 $\pm$ 0.6	51.2 $\pm$ 0.7	53.6 $\pm$ 0.6	55.8 $\pm$ 0.6
B	2	24.5 $\pm$ 0.8	24.8 $\pm$ 0.8	25.9 $\pm$ 0.6	53.3 $\pm$ 1.1	55.7 $\pm$ 0.8	59.5 $\pm$ 0.9
C	NA	16.0 $\pm$ 0.5	19.5 $\pm$ 1.0	22.9 $\pm$ 1.3	56.0 $\pm$ 3.8	70.1 $\pm$ 3.5	83.2 $\pm$ 2.2

^a The average and standard error of all the daily low values recorded throughout the entire observation period.

^b The average and standard error for all recorded values over the entire observation period.

^c The average and standard error of all the daily high values recorded throughout the entire observation period.

Table 2. Correlation of mites per week and proportion of weeks with *T. putrescentiae* in a given trap in five different dry-cured ham aging structures

Company	Room	<i>n</i>	Correlation (<i>r</i> and <i>P</i> -values)*	
A	1	12	<i>r</i> = 0.66	<i>P</i> = 0.02
A	2	8	<i>r</i> = 0.87	<i>P</i> < 0.01
B	1	9	<i>r</i> = 0.76	<i>P</i> = 0.02
B	2	11	<i>r</i> = 0.90	<i>P</i> < 0.01
C	NA	20	<i>r</i> = 0.64	<i>P</i> < 0.01

*Correlation analyses performed with PROC CORR in SAS v. 9.3 (2010).

The proportion of weeks for which a particular trap caught mites was positively and significantly correlated with the mean mites per week at a given trap location (Table 2).

Discussion

The results of this study suggest that the simple, food-baited trap that was developed is able to detect mites and monitor their populations under commercial settings. Up until the beginning of this project, there were no methods available for detecting and monitoring mite populations in ham facilities other than simple observations conducted by employees at dry-cured ham facilities, utilizing their own criteria. This study shows that the trap can provide an early warning of a mite infestation that may not be noticed through visual inspections. Therefore, traps can help determine when a treatment or a corrective action is required to control mites. Mites were detected inside infested ham aging rooms, and the numbers of mites in traps apparently reflected the relative sizes or activity of different mite populations relative to the conditions of various locations in the facilities and across facilities. Compared with the use of pheromone traps for stored product beetles and moths (reviewed in Toews and Nansen 2012), only a few studies have been published on the use of baited traps to monitor stored product mites, including *T. putrescentiae* (Thind and Ford 2004, Thind 2005, Wakefield and Dunn 2005, Wakefield 2006). However, this information is critical for the development of IPM programs (Campbell et al. 2002).

Fumigation with MeBr is currently the most effective method for controlling ham mite infestations (Rentfrow et al. 2006). Our results suggest that the impact of fumigation on ham mite populations can be monitored with the trap that was developed in this study. Mite captures in traps gave useful information on relative mite numbers before fumigation with MeBr, when numbers were high, to directly after treatment, when numbers typically dropped to 0 for one to several weeks. Trapping is therefore useful to monitor mites before and after fumigation to help determine the effectiveness of the

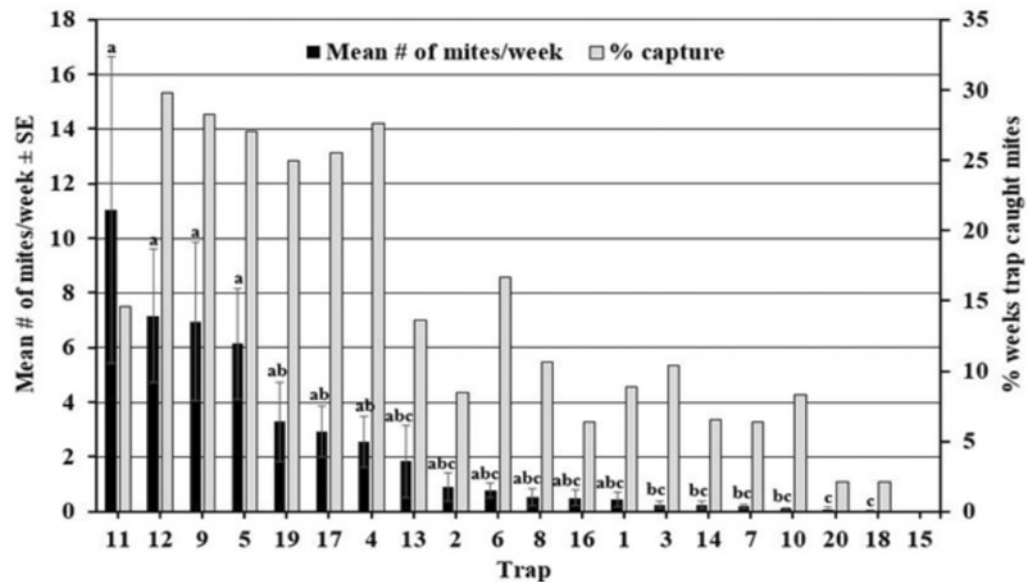
fumigation exercise. Some exceptions to that conclusion in our data may be due to either ineffective fumigations or from an unfumigated source of mites, perhaps from an adjoining space or cracks and crevices either in racks or other indoor structures (Thind 2005, Wakefield and Dunn 2005), as a source of mites that invaded the treated room after fumigation, causing rebound or gradual post-fumigation increases in mite populations (Campbell and Arbogast 2004). *Tyrophagus putrescentiae* has a very high intrinsic rate of natural increase (*r*) of up to 0.4-fold per day depending on the food source, temperature, and RH (Sánchez-Ramos and Castañera 2005, Bahrami et al. 2007) compared with other stored product arthropod pests, such as the rice weevil, *Sitophilus oryzae* (L.) (Coleoptera: Curculionidae), with *r* of 0.06 per day at 30°C (Kangmontree 2005). *Tyrophagus putrescentiae* survivors after fumigation could therefore reproduce and disperse, but surviving populations may not have been high enough to be detected in traps until after 3 wk in Facility A and up to 7 wk in Facility B following fumigation.

Mite populations may also bounce back quickly to pre-fumigation population sizes if less than the recommended MeBr dosage or a fumigant other than MeBr is used. In either case, a significant proportion of a population could remain to reproduce. For instance, we were informed by the management of Facility B that half of the recommended dosage of MeBr was used for the week 28 fumigation of Room 2 (Fig. 8). The average trap count was 0.4 $\pm$ 0.2 mites during the first week after fumigation and this increased substantially to 52.8 $\pm$ 13.7 mites per trap after 2 wk. We therefore presume that a longer exposure time or higher gas concentration may have been required for a more effective fumigation exercise. During fumigation, pest mortality is a function of concentration of that gas, the time exposed to that concentration, and the temperature of the space under fumigation (Phillips et al. 2012). Therefore, it is possible that this room received a suboptimal fumigation due to deficiencies in any one of these variables. This assumption of a poor fumigation, which resulted in a population rebound, is validated, as another fumigation at the same facility with the required concentration of fumigant during week 5 in July 2012 kept the trap counts below two mites per trap for at least 6 wk. In Facility A, trap counts typically remained at 0 for an average of 2 wk after fumigation. However, an average of 15.3 $\pm$ 6.7 mites was caught in traps deployed in week 26, a week after the phosphine fumigation exercise in January 2013. This 1-wk rebound may be due to phosphine being used. Although there have been reports indicating that phosphine may not be as effective as MeBr at eradicating mites (Environmental Protection Agency 2008), other studies (Mueller et al. 2006, Zhao et al. 2015) reported that all life stages of the ham mite are killed by phosphine. The noncomplete kill resulting from this fumigation exercise may therefore have been due to poor application processes.

Table 3. Correlation between trap capture data for *T. putrescentiae* with weekly periods following fumigation in three different commercial dry-cured ham aging structures

Company	Room	Period of weeks	n	Correlations of mite trap data with time after fumigation*			
				Mean mites per trap		% of traps with mites	
B	1	Week 6 to week 60	55	$r = 0.41$	$P < 0.01$	$r = 0.53$	$P < 0.01$
B	2	Week 6 to week 28	23	$r = 0.63$	$P < 0.01$	$r = 0.75$	$P < 0.01$
B	2	Week 29 to week 53	25	$r = 0.18$	$P = 0.39$	$r = 0.24$	$P = 0.24$
C	NA	Week 13 to week 52	32	$r = 0.31$	$P = 0.08$	$r = 0.23$	$P = 0.20$

*Correlation analyses performed with PROC CORR in SAS v. 9.3 (2010).

**Fig. 11.** Trap ranking using mean ($\pm$ SE) number of mites per week caught by each trap (left vertical axis) and percentage of weeks with mite capture in a given trap (right vertical axis) in Facility C for 60 wk. Means with the same letter are not significantly different ($P > 0.05$; by Tukey–Kramer’s honestly significant difference test).

In all five aging rooms studied, trap capture varied significantly with the location of traps (Figs. 6, 9, and 11). Studies have shown that factors such as proximity of trap to the pest (Mullen and Dowdy 2001; Amoah et al. unpublished) and presence or absence of food (Toews and Nansen, 2012) have an effect on capturing storage pests in traps. Nansen et al. (2004) and Toews and Nansen (2012) recommend placing traps along walls, in corners, and/or near the ground, as this may increase trap efficiency. In this study, traps were placed on the floor along the walls, near machinery or other structural edges, or underneath racks or on ledges approximately 1 m above the floor. Differences in trap capture may therefore have been due to the proximity of the traps to a mite or food source and/or differences in the microclimate at trap locations.

Sanitation is an important preventive component in any successful IPM program. Excellent sanitation could therefore impact the population dynamics of *T. putrescentiae* and potentially contribute to low trap counts. Also, sanitation may immediately increase trap capture, as an increase in travel distance for food increases the likelihood of a pest being captured in a trap (reviewed in Toews and Nansen 2012). Although details of the sanitation procedures in all the facilities were not documented, a thorough cleaning and sanitation exercise was documented during week 25 in Facility A. Slightly low trap counts in weeks after that exercise could not be attributed entirely to cleaning because phosphine fumigation was carried out

during that same week. We conducted a brief cursory inspection of Facility C and expected it to have relatively higher mite numbers than others based on the presumed level of sanitation. However, that was not the case, as trap counts were quite low in that building. Concrete explanations about the role of either sanitation or structural characteristics related to numbers of *T. putrescentiae* in traps will require further research. However, it has been reported that aging time of the hams has a greater impact on mite infestations than sanitation of the facilities (Zhao et al. 2016).

This study showed that a mite trap made using a disposable petri dish and a dog food-based bait was effective at detecting ham mites and monitoring their population dynamics in ham processing facilities. Mites caught in traps varied from zero to several hundred, with some areas of the facilities having higher mite activity than other areas. Traps confirmed that fumigation in certain circumstances significantly reduced mite populations. It was also confirmed that mite activity slowly increases after fumigation. Based on this research, mite traps can be distributed in ham facilities and other processing and retail facilities to help monitor mite activity over time and space. Use of traps can be applied in an IPM program to indicate increases in mite populations to plant employees. This could help dry-cured ham plants determine if corrective actions such as fumigation are needed as well as help assess the impact of corrective actions such as fumigation on mite control.

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References Cited

- Adler, C. 2004. Pests of dried fruits, cocoa, and spices in Germany, pp. 19–21. *In* Proceedings, Biocontrol of arthropod pests in stored products, 24–25 May 2004, Athens, Greece.
- Bahrami, F., K. Kamali, and Y. Fathipour. 2007. Life history and population growth parameters of *Tyrophagus putrescentiae* (Acari: Acaridae) on *Fusarium graminearum* in laboratory conditions. *J. Entomol. Soc. Iran* 26: 7–18.
- Boczek, J. 1991. Mite pests in stored food, pp. 55–79. *In* J. R. Gorham (ed.), Ecology and management of food-industry pest. Association of Official Analytical Chemists. Arlington, VA.
- Brazis, P., M. Serra, A. Selles, F. Dethioux, V. Biourge, and A. Puigdemont. 2008. Evaluation of storage mite contamination of commercial dry dog food. *Vet. Dermatol.* 4: 209–214.
- Campbell, J. F., A. K. Dowdy, and M. A. Mullen. 2002. Monitoring stored-product pests in food processing plants with pheromone trapping, contour mapping, and mark-recapture. *J. Econ. Entomol.* 95: 1089–1101.
- Campbell, J. F., and R. T. Arbogast. 2004. Stored-product insects in a flour mill: Population dynamics and response to fumigation treatments. *Entomol. Exp. Appl.* 112: 217–225.
- Clarke, P. G. 2002. The ability of buried PCTM traps to detect stored-product mites in wheat, pp. 390–395. *In* P. F. Credland, D. M. Armitage, C. H. Bell, P. M. Cogan and E. Highley (eds.), Proceedings, 8th International Working Conference on Stored Product Protection. Advances in Stored Product Protection. New York, NY.
- Dunn, J. A., A. J. Prickett, and B. B. Thind. 2005. Assessment of monitoring methods for early detection of three species of storage mites in bulk oilseed rape. *Exp. Appl. Acarol.* 37: 131–140.
- Edde, P. A., M. Eaton, S. A. Kells, and T. W. Phillips. 2012. Biology, behavior, and ecology of pests in other durable commodities, pp. 45–61. *In* D. W. Hagstrum, T. W. Phillips and G. Cuperus (eds.), Stored product protection. Kansas State University, Manhattan, KS.
- Environmental Protection Agency. 2008. Methyl bromide critical use nomination for post-harvest use on dry cured pork products. (http://www.epa.gov/ozone/mbr/CUN2008/CUN2008_Ham.pdf) (accessed 13 December 2014).
- Environmental Protection Agency. 2014. List of critical uses. (<http://www.epa.gov/ozone/mbr/cueinfo.html>) (accessed 15 December 2014).
- Graham, P. P., N. G. Marriott, and R. F. Kelly. 2011. Dry curing Virginia-style ham, p. 8. Virginia Polytechnic Institute and State University, Virginia Cooperative Extension Publication 458-223, Blacksburg, VA.
- Hagstrum, D. W., T. Klejdysz, B. Subramanyam, and J. Nawrot. 2013. Atlas of stored-product insects and mites. AACC International. St Paul, MN.
- Jeong, K. Y., W. K. Kim, J. S. Lee, J. Lee, I. -Y. Lee, K. -E. Kim, J. W. Park, C. -S. Hong, H. Ree, and T. -S. Yong. 2005. Immunoglobulin E reactivity of recombinant allergen Tyr p 13 from *Tyrophagus putrescentiae* homologous to fatty acid binding protein. *Clin. Diagn. Lab. Immunol.* 12: 581–585.
- Kangmontree, B. 2005. Studies of life tables and damages of rice weevil *Sitophilus oryzae* (L.). M.S. thesis, Faculty of Agriculture, Khon Kaen University, Thailand.
- Marriott, N. G., and M. W. Schilling. 2004. Dry cured pork research review, pp. 1–62. *In* Proceedings, 12th Annual National Country Ham Association Meeting, 2–4 April 2004, Morehead City, NC.
- Mueller, D. K., P. J. Kelley, and A. R. VanRyckeghem. 2006. Mold mites *Tyrophagus putrescentiae* (Shrank) in stored products, pp. 1117–1122. *In* Proceedings, 9th International Working Conference on Stored Product Protection, 15–18 October 2006, Campinas, São Paulo, Brazil.
- Mullen, M., and A. K. Dowdy. 2001. A pheromone-baited trap for monitoring the Indian meal moth, *Plodia interpunctella* (Lepidoptera: Pyralidae). *J. Stored Prod. Res.* 37: 231–235.
- Nansen, C., T. W. Phillips, and S. Sanders. 2004. Effects of height and adjacent surfaces on captures of Indianmeal moth (Lepidoptera: Pyralidae) in pheromone-baited traps. *J. Econ. Entomol.* 97: 1284–1290.
- Phillips, T. W., E. M. Thoms, J. DeMark, and S. Walse. 2012. Fumigation, pp. 157–177. *In* D. W. Hagstrum, T. W. Phillips and G. Cuperus (eds.), Stored product protection. Kansas State University, Manhattan, KS.
- Rentfrow, G., D. J. Hanson, M. W. Schilling, and W. B. Mikel. 2006. Methyl bromide use to combat mite infestation in dry-cured ham during production, 108-1 to 108-2. *In* Proceedings, 2006 Annual International Research Conference on Methyl Bromide Alternatives and Emission Reduction, 5–9 November 2006, Orlando, FL.
- Rentfrow, G., D. J. Hanson, M. W. Schilling, and W. B. Mikel. 2008. The use of methyl bromide to control insects in country hams in the Southeastern United States. University of Kentucky Extension/National Country Ham Association. Extension Publication # ASC-171, Lexington, KY.
- Riudavets, J. 2004. Pest problems and their control in stored dried fruits, cocoa and spices, aromatic and medicinal herbs: Description of the status in Spain, pp. 11–12. *In* Proceedings, 4th meeting of COST Action 842: WG4: Biocontrol of arthropod pests in stored products. Athens, Greece.
- Sánchez-Ramos, I., and P. Castañera. 2005. Effect of temperature on reproductive parameters and longevity of *Tyrophagus putrescentiae* (Acari: Acaridae). *Exp. Appl. Acarol.* 36: 93–105.
- Sánchez-Ramos, I., F. Alvarez-Alfageme, and P. Castañera. 2007. Effects of relative humidity on development, fecundity and survival of three storage mites. *Exp. Appl. Acarol.* 41: 87–100.
- SAS Institute. 2002–2010. PROC user's guide, version 9.3 ed. SAS Institute, Cary, NC.
- Thind, B. B. 2005. A new versatile and robust trap for detection and monitoring of stored product pests in the cereal and allied industries. *Exp. Appl. Acarol.* 35: 1–15.
- Thind, B. B., and H. L. Ford. 2004. Management of storage mites in production premises through early detection and monitoring using BT mite traps. *Phytopaga* 14: 733–744.
- Thind, B. B., and P. G. Clarke. 2001. The occurrence of mites in cereal-based foods destined for human consumption and possible consequences of infestation. *Exp. Appl. Acarol.* 25: 203–215.
- Toews, M. D., and C. Nansen. 2012. Trapping and interpreting captures of stored grain insects, pp. 243–261. *In* D. W. Hagstrum, T. W. Phillips and G. Cuperus (eds.), Stored product protection. Kansas State University, Manhattan, KS.
- Toldrá, F., M. Flores, and Y. Sanz. 1997. Dry-cured ham flavor: Enzymatic generation and process influence. *Food Chem.* 59: 523–530.
- Wakefield, M.E. 2006. Storage arthropod pest detection - current status and future directions, pp. 371–384. *In* Proceedings, 9th International Working Conference on Stored Product Protection, 15–18 October 2006, Campinas, São Paulo, Brazil.
- Wakefield, M. E., and J. A. Dunn. 2005. Effectiveness of the BT mite trap for detecting the storage mite pests, *Acarus siro*, *Lepidoglyphus destructor* and *Tyrophagus longior*. *Exp. Appl. Acarol.* 35: 17–28.
- Zhao, Y., S. Abbar, T. W. Phillips, and M. W. Schilling. 2015. Phosphine fumigation and residues in dry-cured ham in commercial applications. *Meat Sci.* 107: 57–63.
- Zhao, Y., S. Abbar, B. Amoah, T. W. Phillips, and M. W. Schilling. 2016. Controlling pests in dry-cured ham: A review. *Meat Sci.* 111: 183–191.