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INFESTATION OF STORED SAW PALMETTO BERRIES BY *CADRA CAUTELLA* (LEPIDOPTERA: PYRALIDAE) AND THE HOST PARADOX IN STORED-PRODUCT INSECTS

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ABSTRACT

The almond moth, *Cadra cautella* (Walker), is a common storage pest known to infest a wide range of dried plant materials, and it has been recorded from a warehouse in Florida during storage of dried passion-flower (*Passiflora incarnata* L.) and dried saw palmetto berries *Serenoa repens* (Bartram) Small. Its status as a pest of stored saw palmetto was confirmed by trapping in a second warehouse used solely for storage of this commodity. The moth occurred in high numbers, captures were closely associated with stacks of bagged berries, and trap catch was very low after the stacks were consolidated under a tarp and fumigated. Yet the results of laboratory rearing on saw palmetto suggested that *C. cautella* has little ability to infest this commodity—development was protracted and highly variable in duration, mortality was high, and pupal weight was low. This sort of contradiction in host suitability, which we refer to as the "host paradox," may be widespread among stored-product insects but has seldom been reported and almost never studied. Published reports suggest that the solution lies partly in dietary supplementation through fungivorous, saprophagous, or carnivorous feeding, although more subtle factors also are suggested. Even cursory observations of the host paradox should be reported to document frequency of occurrence and perhaps stimulate studies directed toward solutions. Such studies would inevitably provide better understanding of population dynamics, which would, in turn, lend support to better management of insects in commercial storage situations.

Key Words: development, saw palmetto, stored-product insects, almond moth

RESUMEN

La polilla de la almendra, *Cadra cautella* (Walker), es una plaga común de almacén que es conocida por infestar un amplio rango de material de plantas secas, y ha sido registrada de una bodega en Florida durante el almacimiento de la flor seca de maracuya (*Passiflora incarnata* L.) y las moras secas del palmito *Serenoa repens* (Bartram) Small. Su estado como una plaga del palmito fue confirmado por medio de trampas puestas en una segunda bodega usadas solamente para el almacimiento de esta material. La polilla ocurre en altos numeros, las capturadas fueron asociadas estrechamente con los apilados de moras embolsadas y el número de polillas capturadas en trampas fue muy bajo después de que los estantes fueron cubiertos bajo una tarpa y fumigados. Aún así los resultos de criar la polilla sobre el palmito en el laboratorio sugiere que *C. cautella* tiene poca abilidad de infestar este material—el desarrollo fue prolongado y altamente variable en duración, la mortalidad fue alta, y el peso de la pupa fue muy bajo. Esta clase de contradicción en el mantenimiento desarrollo sobre el hospedero, lo cual referimos como la "paradoja del hospedero", puede ser ampliamente distribuida entre los insectos de productos almacenados pero raramente ha sida reportada y casi nunca estudiada. Los informes publicados sugieron que la solución consiste parcialmente en la suplementación de dieta por medio de la alimentación fungivora, saprofaga, o carnivora, aunque se sugiere que hay unos factores mas sutiles. Las observaciones precipitadas de la "paradoja del hospedero deben ser reportadas para documentar la frecuencia de ocurrencia y tal vez con ello estimular estudios dirigidos hacia el encuentro de soluciones. Tales estudios definitivemente proveeran un mejor entendimiento de la dinámica de la población, lo cual en cambio, dara apoyo para el mejor manejo de insectos en productos comerciales almacenados.

The almond moth, *Cadra cautella* (Walker), is a common, often serious pest of dried plant materials. It has been recorded from cereal grains and their products, dried fruit, nuts, oilseeds, pulses, and cacao (Richards & Thomson 1932), and also has been reported from dried passion-flower and dried saw palmetto berries (Arbogast et al. 2002).

Saw palmetto, *Serenoa repens* (Bartram) Small, is one of many plants that provide botanicals for the production of pharmaceuticals and herbal supplements. It occurs in the southeastern coastal plain of the United States from South Carolina to Mississippi, where it is a common element of pine flatwoods, mesic hammocks, prairies, and scrubs (Bennett & Hicklin 1998). An extract of the berries, or the ground berries themselves, are reported to be useful in maintaining prostate and urinary tract well-being (Koch 2001), and they are sold for this purpose as a dietary supplement. The berries are harvested by hand from their native habitats during late summer and fall. They are dried to a moisture content of 8-14%, bagged in burlap, and stored pending shipment to end processors. During storage, they are subject to infestation by a variety of stored-product insects.

Arbogast et al. (2002) described the species composition and spatial distribution of an insect population infesting a botanicals warehouse at Mascotte, FL, which was used alternately for storage of dried saw palmetto berries and dried passion-flower (maypop), *Passiflora incarnata L.* *Cadra cautella* was the dominant species, comprising 47% of the insect population when saw palmetto was in storage. To confirm the status of *C. cautella* as a pest of stored saw palmetto, we studied the spatial relationship between adult moths and stacks of bagged berries in a second warehouse used solely for storage of this commodity. We also conducted laboratory experiments to test the hypothesis that successful infestation of the dried berries can be explained entirely by the suitability of this host for growth and development of the moth. The present paper reports the results of these studies and examines the results in the context of host range in stored-product insects, especially the utilization of marginal host commodities.

Materials and Methods

Warehouse Studies

The warehouse, located in La Belle, FL, recently had been acquired for storage of saw palmetto berries and previously had been used for processing and storage of fresh peppers (green bell peppers, jalapeno peppers, etc.). The building was a modern steel structure 40 m wide by 55 m long with a covered dock along the east side (Fig. 1). The only walled areas within the building were restrooms and a small office in one corner and a large cold storage room in another. There were sixteen propane-fired batch driers and a belt drier adjacent to the dock, which served as a work area during drying operations and also for storage of crates and bagged saw palmetto debris, which is used as mulch. In addition to saw palmetto, the building itself contained processing equipment and a few pallets, crates, and burlap bags. The dried and bagged berries were stacked, usually six bags high, on wooden pallets, and the pallets were in turn stacked one on top of another. In January 2001, when we first visited the warehouse, most of the stacks were inside the cold storage room, but there were several small stacks elsewhere (Figs. 1 and 2A). The door to the cold storage room was kept closed, even though the refrigeration was no longer used. In late April, all of the stacks were moved and consolidated in preparation for a commercial fumigation with phosphine (Fig. 2 B-C), which was done under a tarp covering the stacked bags. The fumigation began on April 27, and the warehouse was closed until May 2.

We made three, 24-h trapping runs, one in January, one in late April immediately before the fumigation, and one in early May immediately after the fumigation. The traps were pheromone-baited sticky traps (SP-Locator traps with SP Minimoth pheromone dispensers, AgriSense-BCS Ltd., Pontypridd, Mid Glamorgan, UK). Trap locations were specified in rectangular coordinates with the origin at the southwest corner of the warehouse. The number and configuration of trap locations (Fig. 2A-C) varied slightly. Trap density was increased in areas with stacked commodity, but the spacing between traps was always > 4 m, the measured active space of the lures (Mankin et al. 1999). When trap locations were not occupied by stacks, moth traps were placed 1.2 m above the floor, attached by means of Velcro either to the walls of the warehouse or to the tops of wooden stakes supported by stands on the floor. Otherwise, moth traps were placed on top of the stacked bags or attached to walls slightly above the stacks. Placement of traps under these circumstances was necessarily imprecise, but we estimated that all were within <1 m of their designated coordinates. The stacks ranged in height from slightly over 1 m to about 4.5 m, and trap height varied accordingly.

To determine the spatial distribution of trap catch for each trapping run, the x, y-coordinates of the trap positions and the corresponding numbers of moths captured were entered in Surfer 7 (Golden Software, Golden, CO) for contour analysis. This software posted observed trap catch to the appropriate coordinates on a floor plan of the warehouse, which had been entered as a base map, and then created a denser grid of trap catch values by interpolation, using radial basis functions (with the multiquadric function). This method of interpolation produces good representation of most small data sets (<250 observations) (Golden Software 1999).

Laboratory Studies

Laboratory cultures of *C. cautella* were established in January 2001 with adults collected from the La Belle warehouse. The moths were reared on

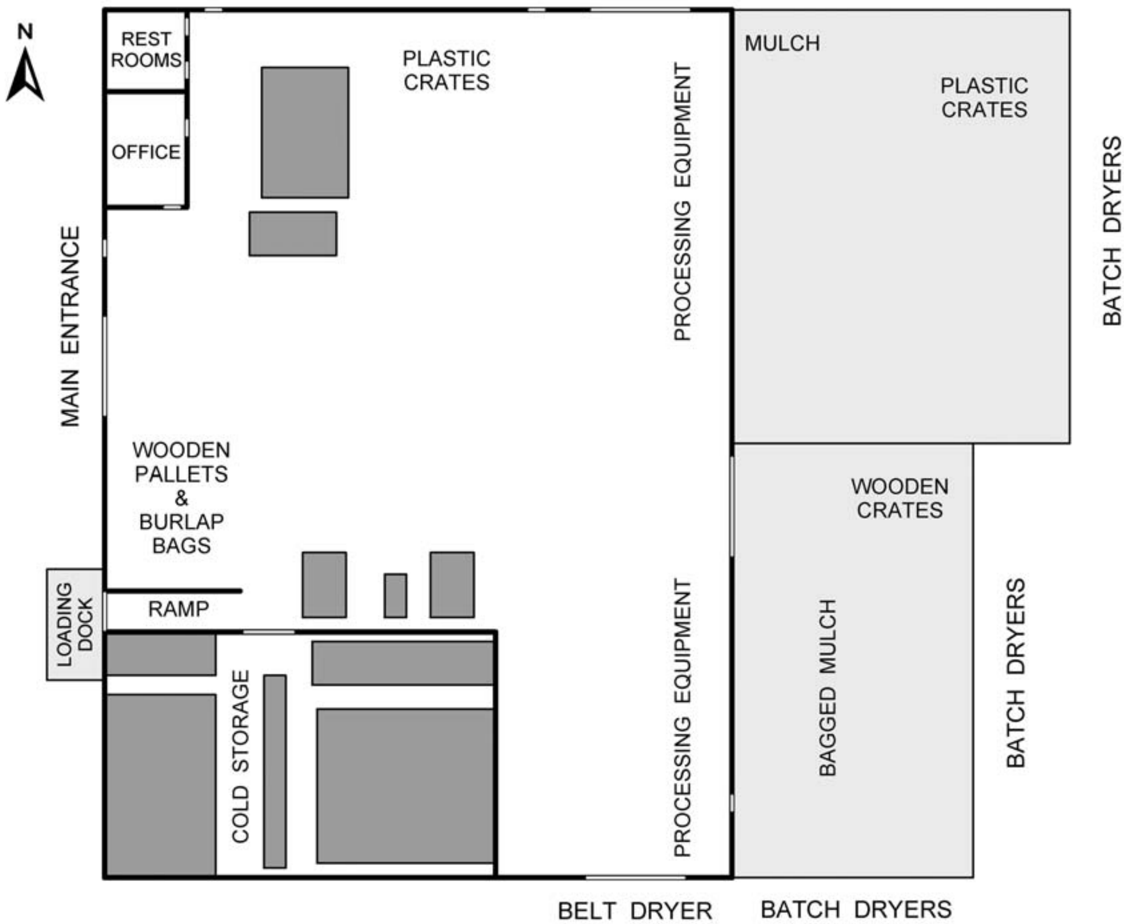

Fig. 1. Floor plan of a botanicals warehouse at La Belle, FL used for drying, bagging, and storing saw palmetto berries. The light gray areas represent docks outside the building. The dark gray areas are stacks of bagged berries on pallets.

a standard laboratory diet (Silhacek and Miller 1972) consisting of ground Gaines dog meal (10%), rolled oats (4%), white cornmeal (26%), whole wheat flour (23%), wheat germ (2%), brewers' yeast (5%), glycerol (16%), and honey (14%). Cultures were maintained in a walk-in environmental chamber (EGC, Chagrin Falls, OH) at 27 ± 1°C and 60 ± 5% RH under a 12:12 h light-dark cycle. All experimental procedures, except moisture determinations, were conducted within the chamber.

To compare developmental time, pupal weight, and survivorship on saw palmetto with that on the laboratory diet, larvae were reared individually on 8 ml of ground saw palmetto in 16 ml Wheaton sample bottles (Wheaton Scientific, Millville, NJ). Ventilation was achieved by a screen-covered opening (2 cm diam) in each bottle cap. The screen consisted of disks cut from extra fine phosphor-bronze cloth (Hillside Wire Cloth Co., Bloomfield, NJ) to fit inside the caps.

Dried saw palmetto berries from the La Belle warehouse were coarsely ground in a blender. These ground berries and the laboratory diet were equilibrated to the relative humidity of the environmental chamber, for which purpose a quantity of each diet sufficient to complete all experiments, as well as provide 6 samples for moisture determination, was placed in clear polystyrene boxes (19.5 × 14.0 × 7.0 cm) (Tri-State Plastics, Dixon, KY) with screened holes (7 cm diam) in the lids. A shallow layer of diet was placed in each box and held in the environmental chamber for one week, during which time it was stirred daily. The diets were then retained in the boxes until they were used for rearing or moisture determination. Moisture content of the diets was determined by an air-oven method, AACC Method 44-15A (American Association of Cereal Chemists 2003), when the first experiment was set up and again when the last experiment was completed.

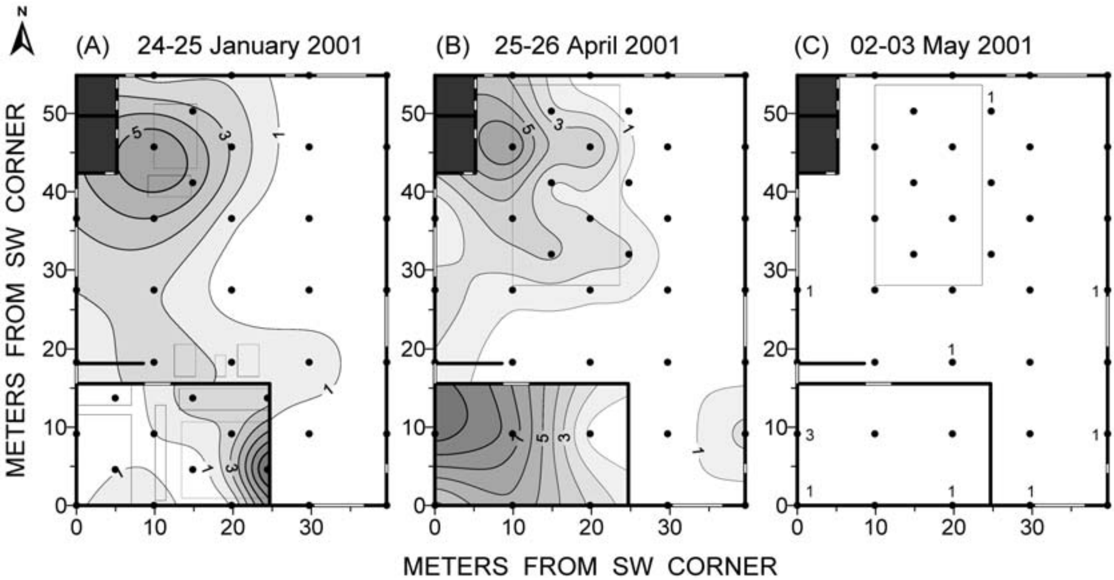

Fig. 2. Spatial distribution of *C. cautella* in a botanicals warehouse as indicated by trap catch of adult males. Trap locations are indicated by dots and locations of stacked bags by rectangular outlines. Contour lines represent total trap catch during a 24-h trapping period. Following fumigation (C), there were too few captures for contour analysis, so trap catch is indicated by numerals adjacent to trap locations. The total number of moths captured during each of the three trapping runs was (A) 65, (B) 78, and (C) 11.

About 8 ml of moisture-equilibrated diet were placed in each of 100 bottles, 50 bottles per diet, and one newly hatched larva was added to each bottle. This procedure was repeated three times at weekly intervals. To obtain larvae, eggs were collected over a 6-8 hr period, confined in petri dishes without food, and held in the environmental chamber. After 2 days, the eggs were checked for hatching every 2-3 hr during the workday, and newly hatched larvae were transferred with a camel hair brush to the bottles with diets. Enough larvae were obtained in this manner during a single day to set up one experiment.

The bottles with larvae were allowed to remain undisturbed for 2 wk and then examined daily for pupation and adult eclosion. When a pupa became fully tanned (light brown), it was gently removed from its cocoon with soft forceps, weighed on an ultra-microbalance (Type UMT2, Mettler Instrument Corp., Hightstown, NJ) with readability to 0.0001 mg, and then returned to the bottle. Observations were continued until all the insects either emerged or died.

Combined data for males and females were used in running statistical tests. Differences in mean survivorship and in pupal weight were analyzed by *t*-tests, the latter after square-root transformation of the data. The data for developmental period failed tests for normality and equal variance, which could not be corrected by any of the common transformations, so the data were analyzed by the Mann-Whitney test (SigmaStat 3.0, Systat Software, Inc., Richmond, CA), which compares median values.

Results

Warehouse Study

The spatial distribution of adult *C. cautella,* as indicated by trap catch, showed a close association of the moths with the stacks of berries (Fig. 2). In late January 2001, most of the berries were stored inside the closed cold room, and the stacks covered much of the floor space (Fig. 2A). The highest trap catch occurred within this room along the east wall. The remaining captures were concentrated on two stacks near the office and rest rooms with captures extending from there to three very small stacks just outside the cold room. Again in late April the highest trap catch occurred inside the cold room (Fig. 2B), from which the berries had been removed a few days earlier. Following fumigation (Fig. 2C), only 11 moths were trapped, 5 inside the cold room and the remainder widely scattered about the warehouse. None were trapped on the stack and only one immediately adjacent to the stack.

Laboratory Study

The moisture content of the laboratory diet (mean ± SE) was 15.2 (± 0.04)% at the beginning of the experiment and 13.9 (± 0.05)% at the end.

The moisture content of the saw palmetto ranged from 10.2 (± 0.07)% initially to 10.1 (± 0.08)% at the end.

Development of *C. cautella* on saw palmetto was protracted and highly variable in duration, mortality was high, and pupal weight was low (Table 1). The median developmental period on saw palmetto was significantly longer (by 60 d) than on laboratory diet (Mann-Whitney test; $P < 0.01$) and pupal weight was significantly lower ($t = 21.60$; $df = 153$; $P < 0.01$). Survival on saw palmetto also was lower than on laboratory diet ($t = 11.75$, $df = 4$, $P < 0.01$). The mean survival rate (±SE) based on three groups of 50 insects was 89.3 ± 4.4 on laboratory diet and 16.7 (±4.4) on saw palmetto. Although no adult moths were weighed or otherwise measured, those that developed on saw palmetto were obviously smaller than those reared on the laboratory diet, as would be expected given the difference in pupal weight.

Discussion

The high numbers of *C. cautella* in the La Belle warehouse, the close association of trap captures with stacks of bagged berries, and the very low trap catch after fumigation of the consolidated stack, provide conclusive evidence that *C. cautella* infests saw palmetto during storage and is, in fact, a major pest. Yet in the laboratory, *C. cautella* displayed little ability to attack saw palmetto. Its protracted development, with high larval mortality and low pupal weight, suggest that populations would increase little, or even decline, on saw palmetto. This contradiction, a phenomenon we term the "host paradox," may be quite widespread among stored-product insects, but has seldom been reported and almost never studied.

Storage insects typically have broad host ranges that include dry commodities of both plant and animal origin, but these commodities differ markedly in their ability to support population growth (Arbogast 1991). Variation in host suitability is well illustrated by studies of the cigarette beetle, *Lasioderma serricorne* (F.), which is an extremely polyphagous stored product insect with reported hosts including tobacco, spices, cereals, pulses, seeds, nuts, dried fruit, dried vegetables, cocoa beans, coffee beans, yeast, bamboo, copra, ginger, licorice root, herbarium specimens, dried fish, fish meal, and meat meal (Howe 1957). In a comparative study of selected plant products, Howe (1957) found a range of 80 d in mean developmental period and 97% in survival rate (at 30°C). In a study of spices, LeCato (1978) observed a range of 100 d in median developmental period and 88% in survivorship (at 28°C). Products such as whole peas, curry powder and chili powder are relatively poor diets for *L. serricorne* and do not support rapid population growth. An additional example of variation in host suitability is provided by a study of three stored-product moths on dried fruits, almonds, and carobs (Cox 1975). The mean developmental period of *C. cautella*, for instance, ranged from 35 d on almonds to 84 d on raisins (30°C). The developmental period of *C. cautella* on the standard laboratory diet in the present study was much shorter than on any of the commodities reported by Cox (1975), even though temperature was lower (Table 1).

Clearly, some commodities are only marginally suitable as hosts for storage insects. They barely support development, but yet these same commodities may become seriously infested in commercial storage. Awareness of this paradox is important in evaluating the potential pest status of stored-product insects; host studies in the laboratory may not reveal true pest potential under commercial storage conditions.

The reasons for this discrepancy and the occurrence of the host paradox may lie partly in dietary supplementation through fungivorous, saprophagous, and carnivorous feeding, which are known to enhance development and population growth, especially on poor host commodities. The foreign grain beetle, *Ahasverus advena* (Waltl), for example, feeds on a wide variety of stored products, including grain and cereal products, but usually oc-

TABLE 1. DEVELOPMENT OF *C. CAUTELLA* FROM EGG HATCH TO ADULT ECLOSION ON LABORATORY DIET AND ON DRIED SAW PALMETTO BERRIES AT 27 ± 1°C AND 60 ± 5% RH.

	Laboratory diet		Saw palmetto	
Development	*n*	Mean ± SE	*n*[1]	Mean ± SE
Males				
Period (d)	55	23.1 ± 0.2	18	84.7 ± 2.9
Pupal wt (mg)	55	14.5 ± 0.25	16	5.3 ± 0.32
Females				
Period (d)	72	23.4 ± 0.2	7	91.6 ± 7.9
Pupal wt (mg)	74	19.9 ± 0.30	7	6.0 ± 0.45

[1]*n*, the number of insects on which the mean is based.

curs in large numbers only when a commodity is moldy. Woodroffe (1962) found that *A. advena* cannot breed successfully on rolled oats or whole wheat flour in the absence of visible mold unless yeast or wheat germ are added, suggesting that some cereal products are deficient in an essential nutrient that can be provided by molds, yeast, or wheat germ. The Indianmeal moth, *Plodia interpunctella* (Hübner), may also require fungal supplementation for development on some of its hosts. This moth is a pest of stored raisins, but fails to develop on raisins in the laboratory unless the grapes used to produce the raisins are inoculated before drying, with a particular fungus known to infect grapes in the field (Charles Burks, personal communication). Burks hypothesized that the conidia of this fungus support neonate larval development, while raisins alone do not. Other storage insects are known to supplement their diet by saprophagous feeding. Thus, population growth of the red flour beetle, *Tribolium castaneum* (Herbst), on several cereal grains increases when dead eggs or adults of *P. interpunctella* are added to the grain (LeCato & Flaherty 1973; LeCato 1975a). Supplementation with dead moth eggs and adults also increases population growth of the sawtoothed grain beetle, *Oryzaephilus surinamensis* (L.), on peanuts, but not on more suitable diets such as corn, wheat, or rice (LeCato 1973). Facultative predation also has been shown to enhance population growth of storage insects. Population growth of *T. castaneum*, for instance, is increased on some commodities by predation on the immature stages of *O. surinamensis* (LeCato 1975b).

Fungus feeding, saprophagy, and predation may sometimes provide the answer to the host paradox, but less obvious factors also can be involved. This is evidenced by the association between field infestation of carobs by the pyralid moth *Ectomyelois ceratoniae* (Zeller) and the ability of *C. cautella* to infest carobs in storage (Dobie 1978). Carob pods crack as they are ripening on the tree and become infested by *E. ceratoniae*, which is attracted by a mold growing in the cracked pods. After harvest, carobs may become infested by a variety of stored-product insects, including *C. cautella*. Dobie (1978) found that previous field infestation has a marked effect on the suitability of carobs as a food for *C. cautella*, an effect that cannot be attributed to mechanical damage, because the carobs used in his experiments were coarsely ground. Ovipositing females and first instars of *C. cautella* show a preference for previously infested carobs, on which survival is much higher. Dobie postulated that factors directly associated with field infestation must render carobs attractive to *C. cautella* and aid in larval development.

Development of storage insects in commercial settings on commodities that fail to support development in the laboratory may occur more commonly than suggested by the meager number of references in the literature. Under-reporting of this phenomenon may arise from a reluctance to publish data perceived to be negative. An incisive discussion on the importance of negative data and the potential consequences for scientific theory of withholding publication can be found in an essay by Gould (1993). Even cursory observations of the host paradox should be reported to document frequency of occurrence and perhaps stimulate studies directed toward solutions. Such studies would inevitably provide better understanding of population dynamics, which would in turn lend support to better management of insects in commercial storage situations.

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