The IPM Practitioner
Monitoring the Field of Pest Management
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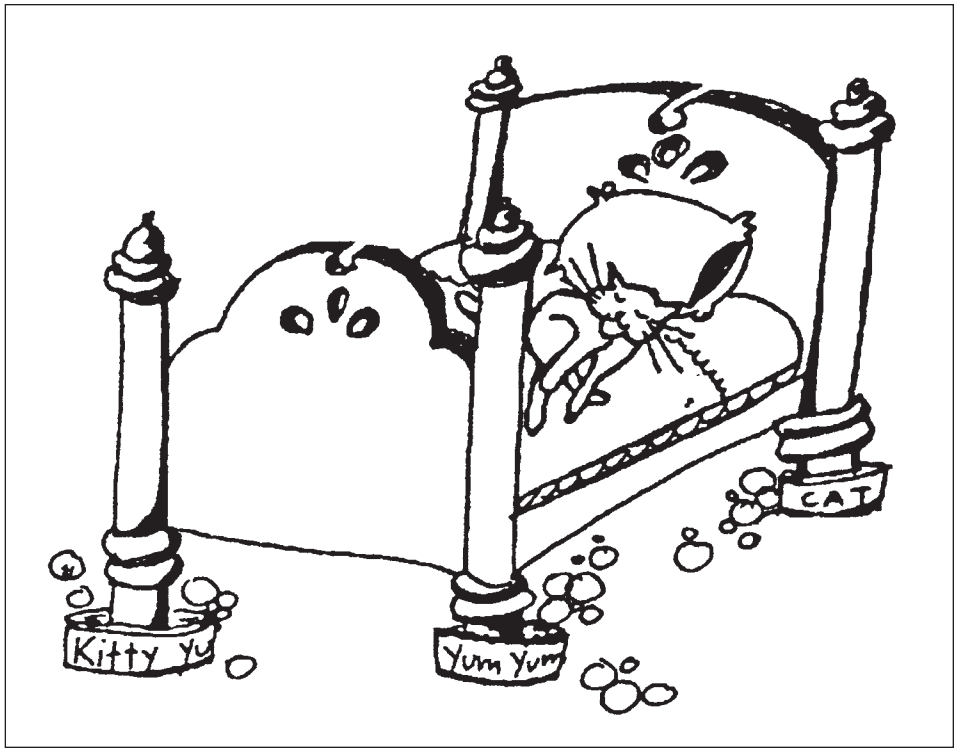
New IPM Methods for Bed Bugs

By William Quarles

Over the past 20 years there has been a resurgence of bed bugs in the U.S. The greatest number of infestations have been found in large U.S. cities, especially New York, Chicago, Philadelphia, and Cinncinnati. Infestations are seasonal, and larger numbers are seen in the summer (Potter et al. 2013a). Homes, apartments, hotels, college dormitories, laundries, hospitals, schools, homeless shelters, and other places have been treated. The resurgence is likely due to pesticide resistance and increased worldwide travel (Reinhardt and Siva-Jothy 2007).

Bed bugs are mostly a nuisance pest. Bugs and bites can cause psychological problems, allergic reactions and asthma (Doggett et al. 2012). So far, they have not been found to vector human pathogens. But bed bugs can pick up bacteria and other microbes from human skin and surroundings and passively spread them to people and the environment (Delaunay et al. 2011; Burton 1963).

Bed bugs are difficult to control because they are resistant to many pesticides. But new IPM programs allow up to 96% reduction in pesticides, and in some cases bugs can be eliminated with non-chemical methods (Singh et al. 2013; Wang et al. 2012b; 2013b). Bed bugs can be treated by an IPM program of prevention, monitoring, vacuuming, traps, repellents, heat and steam treatments, fumigation, and use of reduced risk pesticides such as silica gel, diatomaceous earth, neem, essential oils, and microbials (Schmahl et al. 2010; Potter et al. 2014; Barbarin et al. 2012; Jones 2013; Wang et al. 2014a). We have reported on bed bug problems in earlier issues of the *IPM Practitioner* (Quarles 2007; 2009; 2010). This article has the latest information on IPM methods for bed bug management.



Drawing by Deborah Green

IPM methods including prevention, monitoring, vacuuming, encasements, traps, repellents, heat and steam, cold, fumigation, and reduced risk insecticides can be effective for bed bug management. Traps can protect a bed, preventing bites, and stopping bed bug reproduction.

How Do they Spread?

Bed bugs spread both actively and passively. Active spreading is usually limited to the confines of a structure. A survey of row houses in Philadelphia showed about 11% of residents had encountered bed bugs. The bugs spread throughout a structure, but they did not walk outside and infest the house next door (Mabud et al. 2014). In an infested high rise, they often just walk out the apartment door, down the hall and through the door into the next apartment (Wang et al. 2010; Usinger 1966; Pfiester et al.

In This Issue

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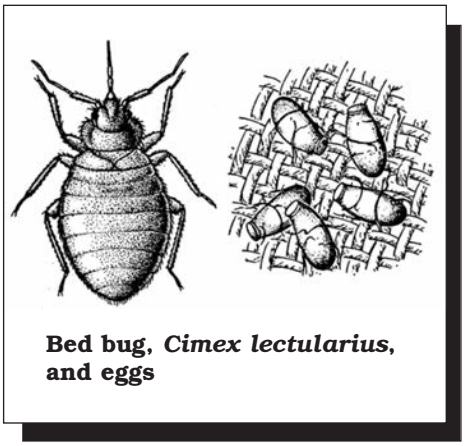
Update

2009). Genetic analysis usually shows that all the bed bugs in a structure are closely related, and infestations may often spring from a single mated female (Booth et al. 2012; Saenz et al. 2012).

Passive spreading occurs when bed bugs hitch a ride on a human host or human possessions. "Bed bugs are transmitted from infested house to unifested house on furniture, baggage, boxes, in suitcases, packed clothing, and bedding" (Snetsinger 1997). This results in transmission of the infestation to public transportation, offices,



Bed bug, *Cimex lectularius*, and eggs

libraries, stores, airplanes, hospitals, schools, and other homes.

Fertilized Females

Bed bugs usually aggregate near feeding sites. Fertilized females avoid these aggregations, possibly to avoid injury from traumatic insemination. They are not attracted to, and do not secrete aggregation pheromones (Pfiester et al. 2009; Quarles 2010). For whatever reason, a dispersing bed bug is more than likely a fertilized female ready to lay eggs (Reinhardt and Siva-Jothy 2007; Schaefer 2000).

So, if you have just brought a bed bug back from your travels, it will most likely be a mated female. She would most likely bite right away, and then you would notice nothing until the next bite, about two weeks later. After biting, she would immediately start laying about three eggs a day, and the eggs would either die or hatch within two weeks. At 18-20°C (64.4-68°F) eggs would go through five nymphal stages that also bite, becoming adults in about four months. At these temperatures, there could be three generations a year. Moving out and hoping they die without food would do no good, since they can live more than a year without feeding. Normally, adults live about 10-12 months. Populations can increase quickly, infestations of 4-200 are the norm, but in one case 5000 were found just on one bed. More on bed bug biology can be found in earlier articles (Quarles 2007; 2009; 2010) and in Usinger (1966), Schaefer (2000), Reinhardt and Siva-Jothy (2007).

Prevention

Prevention is the best bed bug control method. Key to prevention is awareness (Potter 2005). Bed bugs cannot fly. They get to where they are going by walking or passive transport. So it is important to think that any item you bring into your house could be infested with bed bugs. The attractive curbside couch left "free" for pickup should be avoided. Rent-to-use items should be regarded with suspicion. Caution should be your companion on trips to the thrift store. Flip pages of used books to make sure there are no bugs or eggs glued to pages. Reduce clutter around the home. Get rid of picture frames and other hiding places near your bed. Caulk all cracks and crevices and easy hiding places. Bed bugs can be killed by heat, and an ordinary clothes dryer can do the job (Usinger 1966; Potter 2005). (See Box A. Self Help).

Bed Bug Risks

Greatest risk comes from sleeping in an infested motel or hotel, or at a friend's infested apartment. Pesticide resistant strains are showing up at hotels throughout the U.S. For instance, about 700 rooms in 293 hotels in the U.S. were treated for bed bugs in 2007. This number represents an infestation rate of about one room in 100 (Black 2008).

When you check into a motel or hotel, check the mattress and bedding for signs of bed bugs. Look for live bed bugs, skins, and spots on the mattress especially along the seams. If possible, check both sides of the mattress. Bed bugs also will hide behind the headboard. If the headboard is easily removable, it might be worth the effort to remove it and inspect for bed bugs. When traveling, keep luggage off the floor and the bed. Keep suitcases closed, and the bathtub is the safest place for storage. When you return from your trip, vacuum your suitcase, wash or dry clean your clothing. Make sure the suitcase is free of bed bugs and eggs.

Do You Have Bed Bugs?

Bed bugs are usually detected through bites, or by visual sightings of bugs, blood spots, eggs, or castoff skins. But low level infestations are hard to detect. There is a range of host sensitivity from an extreme allergic response to no reaction at all. Only about half of the population notices the first bite, and even then bite reactions may be delayed for 10 days. With repeated encounters, an immune response develops, and itchy bites are sensed faster. But even after repeated bites, about 20% of the population may show no response (Reinhardt et al. 2009). There is

Photo courtesy of Pestec IPM

Ladybug, a bed bug sniffing dog

Box A. Self Help

Leaving the light on will not stop bed bugs from feeding. Taking a vacation from the premises is unlikely to starve them. Turning off the heat in a cold climate will not kill them unless room temperatures reach –17°C (1.4°F) for at least two hours (Usinger 1966; Naylor and Boase 2010). A big mistake is chemical foggers. These pesticides are ineffective against bed bugs, and can expose you to harmful pesticide residues (Jones and Bryant 2012; Jacobson et al. 2011).

If you feel you are at risk, mattress encasements (see Resources), elimination of clutter, and regular cleaning are your best protection. If you have had an infestation, installation of monitoring traps such as Climbup™ to protect your bed seems prudent (see Resources).

You can help with control by making sure that bedding and mattress is not harboring them. Bedding can be washed in hot water and dried in a hot drier. The good news is that washing clothes at 60°C (140°F) is effective against all life stages. Tumble drying in a hot (>40°C; 104°F) dryer for 30 minutes or freezing at –17°C (1.4°F) for 2 hours will kill all bed bugs. Adults and nymphs can be drowned by soaking laundry, but this will not kill the eggs. It takes about 8 hours to disinfest 5 lbs of laundry by putting it in a freezer at –18°C (0.4°F) (Naylor and Boase 2010).

If you are able to protect your bed with mattress encasements and traps, bed bugs will not be able to eat and will not be able to reproduce. Females stop laying eggs after 11 days without eating. Remaining bugs will slowly be removed by the traps (Usinger 1966). This control method will be less successful if there are pets and alternate hosts.

Debugging Your Bed

Check the seams of the mattress for eggs and feces. If you see evidence of bed bugs, use the vacuum cleaner. Once you are done vacuuming, remove the bag, seal in a plastic bag, and discard outside in the trash. Then, you must make sure they are not hiding in the cracks and crevices of the bed. You can inspect with a strong flashlight and use pressurized air to flush them out of harborage.

If bed bugs are found in the mattress or box springs, you do not have to use a conventional pesticide. You can either throw them out, treat them with vacuum, or use a steam cleaner. Box springs can be treated with DE or silica gel. Once you are done, zippered encasements are available for mattresses and boxsprings that will exclude bed bugs (see Resources) (Potter 2005).

Once the bed is decontaminated, to get some relief from biting, you can then isolate the bed from the surroundings. If it is supported by legs, for instance, you can use a sticky tape barrier. Alternately, you can use a barrier of vaseline, but that is somewhat messy (Olkowski et al. 1991). Commercial traps such as Climbup are easier to use (see Resources).

If the infestation is severe, they may have found their way into the cracks and crevices along the baseboard and intersections of the wall with the floor. Cracks and crevices can be treated with DE or silica gel and caulked (Olkowski et al. 1991). Pull up the edges of the carpet and see if you see signs of them. Small amounts of DE could be applied underneath the edge of the carpet. Do not use large amounts of DE in open areas, because you could contaminate the air of your living space with dust. You want to apply it in out-of-the-way places where it will be undisturbed by air. Use freshwater DE that has low crystalline silica content or commercially available silica gel (CimeXa) (Olkowski et al. 1991; Snetsinger 1997; Quarles 2007). (see Resources).

Bed bugs can spread through a structure in the same way as cockroaches. If you have a multiunit infestation, you should try to find out how they are getting from apartment to apartment. Check where pipes are going through walls and caulk around those areas (Ebeling 1975).

some evidence that individuals over 65 may react less, or they are less likely to be bitten. One survey found 42% of those over 65 reported no bites or no bite reactions, despite the confirmed presence of bed bugs (Potter et al. 2010).

Low level infestations can be detected by bed bug dogs or traps (see below). Dogs represent a costly investment for a pest control company. Bed bug traps can be less expensive and may be a reasonable alternative (see Resources). A styrofoam cup full of dry ice placed in a pet food bowl dusted with talcum powder can be an effective homemade trap. The Verifi™ or Climbup™ traps are inexpensive and effective (Pfiester et al. 2008; Pinto et al. 2007; Wang et al. 2009a; Quarles 2009; Anderson et al. 2009).

Inspection, Vacuuming, Encasements

Inspection, vacuuming and encasements are key components of an IPM Program and can be done without professional help. (See Box A. Self Help). Zippered encasements can keep bugs from infesting mattresses and box springs (see Resources). Permethrin treated encasements (Active Guard™) are also available. These can kill susceptible bed bugs, but have little effect on permethrin resistant populations (Jones et al. 2013).

Repellents

It is very difficult to repel a hungry bed bug. A folklore repellent is spreading bug bane, *Actaea cimicifuga*, around your bed. In Africa foliage from the bushes *Pseudarthna hookeri* or *Laggera alata* placed under bedding is reputed to stop bed bugs. Pesticides such as pyrethroids will not repel them. Deet (15%) gives some protection, but you have to apply it to your whole body (Wang et al. 2013a; Mossop 1940; Usinger 1966; Moore and Miller 2006). Eucalyptus oil from *E. saligna* will kill them, so lemon eucalyptus mosquito repellent might be effective (Schaefer 2000). The natural compound isolongifolenone has strong repellent action (Wang et al. 2013a). Dusts such as diatomaceous earth and silica gel are repellent (Ebeling 1971). While chemical repellents can be useful, ultrasonic repellers are not effective (Yturralde and Hofstetter 2012).

Pheromones

Bed bugs secrete aggregation pheromones and semiochemicals that are useful in monitoring traps (Weeks et al. 2013; Weeks et al. 2011). The best aggregation pheromone so far is a five-component blend of *E*-2-hexenal, *E*-2-octenal, 2-hexanone, dimethyl disulfide, and dimethyl trisulfide. Histamine secreted by the bugs functions as an arrestant to keep them in harborage (Gries et al. 2014). The first two chemicals in the correct proportions also function as a bed bug alarm pheromone (Liedtke et al. 2011; Quarles 2009).

Heat and Steam

A survey of pest companies nationwide found that about 42% of companies use physical controls such as heat, steam, or freezing for bed bugs (Gangloff-K. et al. 2006). Puckett et al. (2013) found that steam treatments in a laboratory arena killed 100% of eggs and 88-94% of adults and nymphs. In the field, steam is applied in cracks, crevices, door and window moldings or other hiding places. Steam has also been used to decontaminate mattresses and box springs (see Resources).

Hot air was used in the past to kill bed bugs, and convective heater technology is available today. Heat is produced by electric or propane heaters (see Resources). Rooms are heated a minimum of three hours at 140°F (60°C) (Ross 1916; Gunn 1933; Miller 2002; Quarles 2006). Heat can reach lethal levels inside mattresses, pillows, wall voids, books and all contents within a given habitation. Death of life stages is a function of time and temperature. A temperature at about 48°C (118°F) is quickly lethal to adults, whereas death at 45°C (113°F) takes about 95 min. Eggs are killed at 48°C (118°F) for about 72 min (Kells and Goblirsch 2011). Bugs not killed by high temperatures are immobilized (Pereira et al. 2009). Non-lethal heat treatments can also reduce reproduction by killing bed bug symbionts (Chang 1974).

Cold Treatments

Though it is harder to kill bed bugs with cold than with heat, dry ice can disinfest clothing sealed in containers or garbage bags. This treatment destroys eggs and all stages of the bed bugs. A commercial machine (Cryonite™) is available to produce dry ice "snow" that kills bugs on contact (Pinto et al. 2007).

Dry ice is used as a cold source in the U.S., but Italians have had success through treatments with liquid nitrogen. The liquid nitrogen

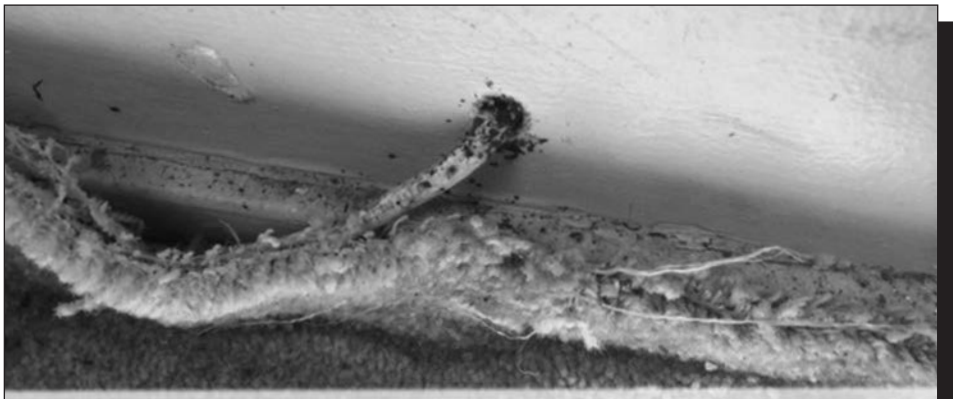


Photo courtesy of Pestec IPM

Holes in walls should be caulked to prevent bed bug travel, and areas underneath carpet edges should be treated.

percolates through pillows and carpets, killing bed bugs. It is the method of choice for many Italian hotels (Biancolini and Pampiglioni 2011).

Carbon Dioxide

Carbon dioxide (CO_2) is important in bed bug control. Dry ice is used to kill bed bugs through low temperatures (Pinto et al. 2007; Olson et al. 2013). It can also be used as a fumigant. Dry ice can be added to plastic garbage bags or boxes full of belongings. Bugs and eggs can be killed within 12 hours, but 24 hours is often needed in field operations (Martin and Henderson 2013; Wang et al. 2012a). Carbon dioxide is also the best attractant for bed bug traps (Wang et al. 2009abc).

Pesticide Resistance

Bed bugs were resistant to DDT when it was banned in the U.S. DDT resistance led to similar problems with other pesticides, such as pyrethroids (Zhu et al. 2010). In fact, field strains of bed bugs are resistant to most currently available pesticides. They are resistant to combinations of neonicotinoids and pyrethroids (Gordon et al. 2014) and to IGRs such as methoprene and hydroprene (Goodman et al. 2013). Though chlorfenapyr residuals can kill some bed bugs, its actions are very slow (Romero et al. 2010). Dust and fumigant formulations are more effective than spray residual products (Koganemaru and Miller 2013; Anderson and Cowles 2012). Lack of an effective residual pesticide has made bed bugs notoriously difficult to control (Mallis and Miller 1964; Usinger 1966; Bloomquist 1996; Moore and Miller 2006).

Reduced Risk Insecticides

Bed bugs are not resistant to some reduced risk insecticides. A neem formulation (CirKil®) is registered for bed bug control. Neem has very low toxicity. Drawbacks are the CirKil formulation has a noticeable odor, and multiple applications may be needed to rid a house of bed bugs. One field experiment showed that most of the bugs were destroyed with one application, but four treatments were needed to kill all the bugs. The infestation was monitored with Climbup™ and Verifi™ traps (see below) (Jones 2013).

Essential oils are being tested for bed bug control. They have the advantage of low toxicity and have potential as fumigants. In a laboratory experiment, clove oil or methyl salicylate fumigants killed bed bugs in about 30 hours at 26°C (78.8°F) and 8 hours at 40°C (104°F) (Choe 2012). Commercial essential oil formulations such as EcoRaider™ (geraniol, cedar oil, detergent) and Bed Bug Patrol™ (clove oil, peppermint oil, detergent) killed >90% of nymphs exposed to a direct spray. Direct sprays of EcoRaider caused 87% egg mortality. In field tests in apartments, EcoRaider gave about 92% reduction of bed bugs, efficacy similar to Temprid® (imidacloprid + *beta*-cyfluthrin) and Demand® (*lambda*-cyhalothrin) (Singh 2012; Singh et al. 2014; Wang et al. 2014b).

The Climbup™ trap prevents bed bugs from climbing onto a bed.

Photo courtesy of Susan McKnight

Another reduced risk insecticide is Alpine® (dinotefuran). Alpine can be applied as a spray or dust. When combined with IPM methods, bugs can be effectively managed with about 95% reduction in applied pesticide (Singh et al. 2013). (see below).

Bed bugs can be killed by fungi. One experiment has shown that *Beauveria bassiana* has great potential as a commercial treatment for bed bug control. Exposed bed bugs carry the infection to others. When only 50% of bed bugs in a laboratory colony were exposed, >95% died within 3-5 days (Barbarin et al. 2012). Penn State University is working on development and registration of the product (Jenkins 2014).

Amorphous Silica

Amorphous silica such as diatomaceous earth (DE) and silica gel can be useful in an IPM program. Potter et al. (2013b) tried using DE as a standalone treatment against bed bugs in six apartment houses in Kentucky. Their treatments led to poor efficacy (Potter et al. 2013b). In contrast, Potter et al. (2014) found that silica gel could be an effective standalone treatment for bed bugs. Six apartments with mean bug infestations of 390 were treated with silica gel dust. Silica gel (CimeXa®) was applied with a soft paint brush to mattresses and to beds. Areas underneath the edge of carpets, and underneath furniture were treated with a total of 1-3 oz (28.3-84.9 g) per apartment. Results were about 82% bug reduction in one week and about 98% reduction in six weeks. Sprays of silica gel in water were less effective. Dusts provide an effective residual and can be spread from bug to bug and into harborages by horizontal transfer (Akhtar and Isman 2013).

Bed Bug Traps

Bed bug traps of several kinds are in use. Sticky traps can be useful for monitoring. There are folklore reports of trapping bed bugs in bean leaves spread on the floor. This information has been verified, and bed bugs are impaled on leaf hairs (trichomes). Research is underway to develop synthetic analogs (Szyndler et al. 2013). Other successful traps are pitfall traps (Climbup®) and baited traps of various kinds (Verifi®, Nightwatch®, CDC-3000®, Bed Bug Beacon®). Bait can be carbon dioxide, heat, pheromones, kairomones, or a human (Wang et al. 2009abc; Singh et al. 2012; Anderson et al. 2009; Wang et al. 2011).

Baited Pitfall Traps

Wang et al. (2009a) tested simple pitfall traps baited with carbon dioxide (CO_2), heat, and chemical cues such as lactic acid and octenol. The carbon dioxide (CO_2) source was dry ice in a cup. In tests within small arenas (56x44 cm; 22x17 in), within 6 hours CO_2 captured about 80% of bed bugs released into the arena. Heat captured about 52%; heat plus CO_2 caught about 87%; and heat, CO_2, plus chemical lure caught about 89%.

In a larger arena (3.1x1.8m; 10x6 ft), a pitfall trap baited with CO_2, heat, and chemical lure caught about 57% of the bed bugs overnight. These traps were also effective in infested apartments. Four apartments were visually inspected for bed bugs, and the average infestation rate was about 12/apartment. These bugs were removed, and one trap was left overnight in each apartment, catching an average of 15 additional bed bugs. A trap left in an unoccupied apartment for 13 days caught 505 bugs (Wang et al. 2009a).

Singh et al. (2012) found a chemical lure of nonanal, 1-octen-3-ol, spearmint and coridander oil significantly increased catches of a monitor baited with CO_2. Heat was less important than chemical lures and CO_2.

Interceptors with Human Bait

One of the best bed bug traps is the bed bug interceptor (Climbup®). This is a pitfall trap that uses humans as bait. From carbon dioxide and other clues, bed bugs know that their favorite host is sleeping on a bed. Their natural tendency is to climb up onto the bed and start biting. Each leg of the bed is placed into an interceptor, which is basically two concentric plastic bowls.

The original bed bug interceptors tested by Wang et al. (2009b) were able to trap an average of 220 bed bugs in each apartment tested. The trap was superior to visual inspection in finding bed bugs, as an average of 39 bed bugs was found visually and about 220 were found in the traps (Wang et al. 2009b).

In another test, when 13 apartments were visually inspected for bed bugs over a 10 week period, the average count per apartment was 6.7 bugs—the interceptors found an additional 8.8 bed bugs per apartment (Wang et al. 2009c).

Commercial Baited Traps

Anderson et al. (2009) tested a commercial prototype (Nightwatch®) host attractant trap (see Resources). Traps were baited with CO_2, heat, and chemical lures. Traps were tested in a square laboratory arena (183 cm x 183 cm; 6ft x 6ft) and field tested in bed bug infested apartments. The most important attractant was CO_2. Traps with CO_2 caught 5898 bedbugs, those without 656. In the laboratory experiments with controlled bed bug releases, traps with CO_2 caught 80-87% of the bugs, traps without CO_2 caught 55-62%. A CO_2 trap in an unoccupied bedroom caught 50 bed bugs over 3 days. Trapping over 31 days showed an exponential decline in the number of bugs caught. In one apartment, this commercial trap removed 10,000 bed bugs. Another trap called the CDC 3000, which also uses host attractants as bait, is also commercially available (see Resources).

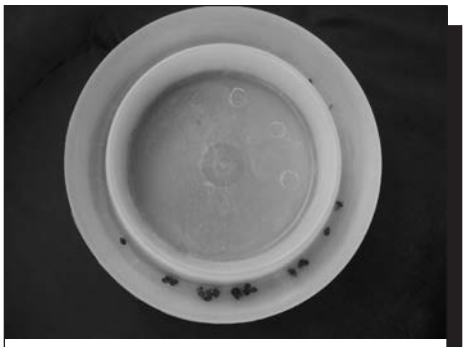


Photo courtesy of Dr. Changlu Wang

Bed bugs cannot escape from the Climbup™ trap.

Direct Comparisons

Wang et al. (2011) found that over a one day period a simple dry ice baited trap was more effective than CDC or Nightwatch traps. When tested over a period of a week, the Climbup trap was just as effective as the dry ice trap operated for one day and more effective than Nightwatch or CDC traps operated for one day. Climbup traps are more effective than visual inspection, and have the advantage of low cost and ease of use (see Resources).

The Verifi Trap

The Verifi Trap uses carbon dioxide, two pheromones and one kairomone as attractants. In a field experiment the trap successfully detected bed bugs in 14 of 17 infested rooms, about the same success as dry ice detectors and dogs. The carbon dioxide comes from a chemical reaction and must be recharged every 24 hours. The pheromones and kairomone last 90 days. The trap has an attractant range of about four feet, and is more useful for confirming bed bugs than removing an infestation (McKenna 2011; Jones 2011).

Bed Bug IPM with Traps

In one of the most thorough IPM tests, an IPM dust regime was compared to an IPM spray. Sixteen infested apartments initially containing an average of about 70-80 bed bugs by visual inspection were divided into two groups of 8 apartments. Both groups were treated with steam, vacuuming, mattress and boxspring covers. Residents were educated about bed bugs, told to reduce clutter, and instructed to wash bedding.

In one group (D-IPM) bed frames, sofa, baseboards and molding were treated with diatomaceous earth (Mother Earth D). Interceptor traps were used with this group. The other group (S-IPM) received sprays of chlorfenapyr in addition to the basic IPM treatment. No interceptor traps were used.

D-IPM apartments showed an average 97.6% bed bug reduction and S-IPM showed a 89.7% reduction after 10 weeks. The dust IPM program was less expensive

($463/apartment) than the spray IPM program ($482/apartment).

The bed bug traps removed an average of 219 bed bugs from each apartment over the 10 week period. In both treatments, bed bugs were completely eliminated from about 50% of the apartments. At the end of the study no one complained of bites, despite the continuing infestation in half of the apartments (Wang et al. 2009a).

IPM and Non-Chemical Methods

In the hands of a dedicated practitioner, non-chemical methods can be very effective for bed bugs. Wang et al. (2012b) tested three treatment regimes, non-chemical methods, insecticides only, and IPM methods that included both. After 10 weeks, bed bugs had been eliminated from 67% of non-chemical, 33% of insecticide, and 44% of IPM apartments. The non-chemical treatments were used only in lightly infested apartments. IPM and insecticide apartments had similar initial numbers of bugs.

IPM and Insecticides

Singh et al. (2013) found that using a complete IPM program of education, steam, bagging infested linens, using interceptor traps, and the reduced risk insecticide Alpine® (dinotefuran) allowed a 96% reduction in applied pesticides needed to control a bed bug infestation in low income apartments. Bed bugs were reduced by 96%, but complete elimination was seen in only three apartments.

IPM and Dust Bands

One experiment tested application of insecticidal dusts Tempo® (1% *beta*-cyfluthrin) in 3.8 cm (1.5 in) wide bands on legs of furniture. Insecticidal bands plus sprays of the reduced risk pesticide Alpine were compared with an IPM treatment of dust bands plus hot steam, mattress encasements, interceptor traps, application of dust in room perimeters, and sprays of Alpine on live bugs. A "control" was the normal insecticide treatment of a pest control company. Over a 12 week period, the band treatment reduced bed bug levels by 95%, IPM 92%, and control 85% (Wang et al. 2013b).

Conclusion

Because of resistance, insecticide only treatments for bed bugs will likely fail. The best hope is an IPM program using components such as prevention, monitoring, vacuuming, traps, repellents, heat and steam, fumigation, and use of reduced risk pesticides such as silica gel, diatomaceous earth, neem, essential oils, and microbials. Even with all these options, complete elimination of bed bugs from a structure is very difficult.

Resources

Amorphous Silica

CimeXa (silica gel)—Rockwell Labs, 1257 Bedford Rd., North Kansas City, KS 64416; 866/788-4101, 816/283-3167, Fax 816/283-3173; www.rockwelllabs.com

Mother Earth Dust (DE)—BASF Professional Pest Control, 26 Davis Drive, PO Box 13528, Research Triangle Park, NC 27709; 800/327-4645, 919/547-2000; http://pestcontrol.basf.us

Essential Oils

Bed Bug Patrol (clove, peppermint, detergent)—Bed-Bug.net, 866/371-2499; www.bed-bug.net

EcoRaider (geraniol, cedar, detergent)—EcoRaider USA, www.ecoraiderusa.com

Encasements

Protect a Bed, BugLock—Protect A Bed, 1500 South Wolf Rd., Wheeling, IL 60090; 866-297-8836; www.protectabed.com; Bed Bug Central, www.bedbugcentral.com (Walmart, Target, many suppliers)

Heat and Steam

Pest-Heat (propane)—Pest Heat, 900C Tryens Rd., Aston, PA 19014; 610/558-0837; 877/234-5630; www.pestheat.com

Thermal Remediation (electric)— Temp-Air, 3700 West Preserve Blvd, Burnsville, MN 55337; 800/836-7432, Fax 952/707-5221; www.thermalremediation.com

Thermapure (propane)—Thermapure/TPE Associates, 180 Canada Largo Road, Ventura, CA 93001; 800/375-7786, Fax 805/648-6999; www.thermapure.com

Jiffy Steamer (steam)—Jiffy Steamer, PO Box 869, Union City, TN 38281; 731-885-6690; Fax 731-885-6692; www.jiffysteamer.com

Cold

Cryonite—Stern Environmental, see below

Traps

Bed Bug Beacon (CO_2)—PackTite, www.packtite.com

Bed Bug Alert (semiochemicals)— Bird-X Inc., 300 N. Oakley Blvd., Chicago, IL 60612; 800/735-0496, 312/226-2473, Fax 312/226-2480; www.bird-x.com

Climbup (pitfall)—Susan McKnight, Inc. PO Box 11406, Memphis, TN 38111; 901/848-3831, Fax 901/324-4035; www.insect-interceptor.com

Verifi (CO_2, pheromones)—FMC Professional Solutions, www.fmcprosolutions.com

Nightwatch (CO_2, heat, semiochemicals)—Biosensory Inc., Belding Mill Complex, 107 Providence St., Putnam, CT 06260; 860/928-1113, Fax 860/928-2720; www.biosensory.com

CDC 3000 (CO_2, semiochemicals)—Cimex Science, www.cimexscience.com; Stern Environmental, 30 Seaview Drive, Seacaucus, NJ 07094; 201-3019-9620; www.sternenvironmental.com

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Update

Susceptibility of *Cimex lectularius* to pyrethroid insecticides and to insecticidal dusts with or without pyrethroid insecticides. *J. Econ. Entomol.* 105(5):1789-1795.

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Calendar

January 5-8, 2015. Advanced Landscape Plant IPM PHC Short Course. University of Maryland. Contact: A. Koeiman, Dept. Entomology, 4112 Plant Sciences Building, University Maryland, College Park, MD 20742; 301-405-3913; akoeiman@umd.edu

January 7-9, 2015. Global Bed Bug Summit, Denver, CO. Contact: NPMA, 10460 North St., Fairfax, VA 22030. www.npmapestworld.org

January 21-24, 2015. 34th Annual EcoFarm Conference. Asilomar, Pacific Grove, CA. Contact: Ecological Farming Association, 831/763-2111; info@eco-farm.org

January 23-25, 2015. NOFA 33rd Annual Organic Farming and Gardening Conf. Saratoga Springs, NY. Contact: NOFA, 585/271-1979; www.nofany.org

January 30-February 3, 2015. Annual Conference, Association Applied Insect Ecologists, Napa, CA. Contact: www.aaie.net

February, 2015. Annual Meeting Weed Science Society of America. Lexington, KY. Contact: www.wssa.net

February, 2015. 26th Annual Moses Organic Farm Conference. La Crosse, WI. Contact: Moses, PO Box 339, Spring Valley, WI 54767; 715/778-5775; www.mosesorganic.org

March 2015. California Small Farm Conference. Contact: www.californiafarmconference.com

March 24-26, 2015. 8th Intl. IPM Symposium. Salt Lake City, UT. Contact: Elaine Wolff, Wolff1@illinois.edu

June 25-27, 2015. Pest Control Operators CA, Monterey, CA. Contact: PCOC, 3031, Beacon Blvd, W. Sacramento, CA 95691; www.pcoc.org

August 1-5, 2015. American Phytopathological Society Conference, Pasadena, CA. Contact: APS, 3340 Pilot Knob Road, St. Paul, MN 55121; 651-454-7250; aps@scisoc.org

August 9-14, 2015. 100th Annual Conference, Ecological Society of America, Baltimore, MD. Contact: ESA, www.esa.org

October 20-23, 2015. NPMA Pest World, Nashville, TN. Contact: NPMA, www.npmnpestworld.org

November 15-18, 2015. Annual Meeting, Entomological Society of America, Minneapolis, MN. Contact: ESA, 3 Park Place, Suite 307, Annapolis, MD 21401; 301/731-4535; www.entsoc.org

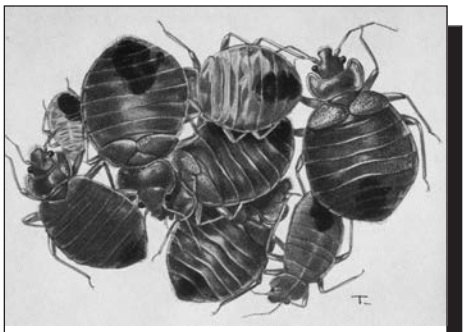
Can Bed Bugs Carry Ebola?

By William Quarles

Bed bugs have been closely associated with humans for thousands of years. During this time, the relationship between humans, bugs, and microbes has been optimized. Microbes and bugs have adapted to mutual advantage. Microbes do not usually kill bed bugs, and in the extreme case, microbes become bed bug symbionts (Nikoh et al. 2014; Hosokawa et al. 2010). And like any good parasite, bed bugs do not kill their hosts by vectoring deadly pathogens. This is the situation for all microbes encountered so far (Doggett et al. 2012). Though bed bugs have never been shown to vector pathogens to humans, there is a great deal of suspicion that they might (Delaunay et al. 2011). Much of the suspicion is based on publications produced over the last century. The information in these publications allow us to answer a number of questions (Burton 1963).

Do Bed Bugs Carry Pathogens?

Bed bugs can carry pathogens on their bodies and in their bodies. They can also excrete pathogens (Doggett et al. 2012). For example, bed bugs pick up bacteria from human skin. Surface swabs of bed bugs show gram positive bacteria such as *Staphyloccocus*, *Micrococcus*, and *Kocuria* (Cockburn et al. 2013). *Burkholderia multivorans* has been found in U.S. field populations (Saenz et al. 2013). Methocillin Resistant *Staphyloccocus aureus* (MRSA) has been isolated from bed bugs in homeless shelters. The pathogen was likely picked up from human skin (Lowe and Romney 2011). About 45 human pathogens have been found associated with bed bugs. These include *Coxiella burnetii*, which causes Q fever; *Trypanosoma cruzi*, which causes Chagas disease; and viruses such as hepatitis B and human immunodeficiency virus (HIV) (Delaunay et al. 2011).



Drawing from Usinger 1966

Bed bugs, *Cimex lectularius*, can carry microbes, on, and in their bodies.

Bed Bug Microbiome

Bed bugs have also evolved relationships with beneficial microbes. *Wolbachia* and other mutualists synthesize vitamins and help with bed bug reproduction. *Wolbachia* is inherited, and bed bugs do not have to pick up a new source all the time. The evolutionary origin goes back millions of years. The biosynthetic genes for B vitamins were transferred horizontally to *Wolbachia* from a coinfecting microbe, probably *Carndinium* or *Rickettsia* (Sakamoto and Rasgon 2006ab; Hosokawa et al. 2010; Meriweather et al. 2013; Nikoh et al. 2014).

Do Pathogens kill Bed Bugs?

Although bed bugs have adapted to many pathogens, some pathogens will kill them. Bed bugs become infected through ingestion, breathing, and sexual transmission of microbes. Common fungi such as *Aspergillus* can be deadly (Strand 1977). This susceptibility has led to research on fungi as control agents. One experiment has shown that *Beauveria bassiana* has great potential as a commercial treatment for bed bug control. Exposed bed bugs carry the infection to others. When only 50% of bed bugs in a laboratory colony were exposed, >95% died within 3-5 days (Barbarin et al. 2012). Penn State University is working on development and registration of the product (Jenkins 2014). Bed bugs are also killed by anthrax, *B. anthracis*; pneumonia, *Diploccocus pneumoniae*; and plague, *Pasteurella pestis* (Burton 1963).

Can Bed Bugs Vector Pathogens?

According to Goddard (2009), "no study to date has demonstrated bed bug vector competence, the ability to acquire, maintain, and transmit an infectious agent..." However, there are many studies that show bed bugs are able to ingest pathogens and that some pathogens, such as hepatitis B, can persist for 5-6 weeks. Hepatitis B and *T. cruzi* are found in bed bug excrement. In some cases, such as Q fever, *C. burnetti,* the pathogen persists and is transmitted from one bed bug stage to another. Other pathogens such as yellow fever are destroyed quickly by the bed bug immune system (Burton 1963; Blow et al. 2001; Delaunay et al. 2011). Though vector competence for human transmission has never been proven, a recent study found that bed bugs could successfully vector Chagas disease, *T. cruzi*, to mice in the laboratory. The infection was spread when mice ingested infected bed bugs, and through bed bug feces on mice skin (Salazar et al. 2014).

Kinds of Transmission

There are two kinds of pathogen transmission, biological and mechanical. Biological vector competence depends on the insect successfully acquiring, absorbing the pathogen from the gut, amplifying it, and sending it back to the salivary glands where it can be injected into the bloodstream of a host. At each stage, there are barriers to this process. But even if the

pathogen is not absorbed, biological amplification can occur in the gut, resulting in infectious secretions (Doggett et al. 2012).

An example of mechanical transmission occurs when a cockroach picks up pathogens on its body or feet, and transmits them to humans by walking on food. Or a crushed tick can lead to a skin infection. Passive or mechanical spread is called phoresy (Delaunay et al. 2011).

Bed bugs are capable of mechanical transmission, where a pathogen escapes in bed bug excrement or a crushed bed bug, then is passed on when the host scratches a bite. There are strong suspicions that hepatitis B or staph infections might be mechanically transmitted by bed bugs (Blow et al. 2001; Delaunay et al 2012; Lowe and Romney 2011). Chagas disease can be transmitted to mice in this way (Salazar et al. 2014).

Why Don't Bed Bugs Transmit Pathogens?

Cockroaches carry pathogens from filth to food, ticks and mosquitoes vector pathogens, and bugs closely related to *C. lectularius* can transmit human pathogens, causing disease. For instance, swallow bugs can vector arboviruses, and arboviruses have been found in bat bugs (Adelman et al. 2013; Goddard 2012). So why don't bed bugs transmit pathogens?

There are five major reasons that bed bugs do not generally vector disease. One, when they bite, they release digestive enzymes that may inactivate some pathogens. Two, when females undergo traumatic insemination, they can be infected. The females that survive have strong immune systems (Doggett et al. 2012). Three, bed bugs have a dedicated host. Although they will attack chickens, pets, and bats, they prefer humans. This specialization prevents the diseases that occur when an insect picks up a pathogen from one species and transmits it to another with devastating results. For instance *Culex* mosquitoes pick up West Nile virus from birds and transmit it to humans (Goddard 2012). Four, for some of the most severe diseases, such as plague, the bed bug may be killed by the disease before it can be passed on (Burton 1963; Strand 1977). Five, a bed bug feeds about every two weeks. The bed bug has two weeks to excrete or inactivate a pathogen before the next bite. This delay prevents buildup of a pathogen from simple feeding (Usinger 1966).

Can Bed Bugs Carry Ebola?

Despite all the reassurances from medical entomology experts, the lingering fear remains that bed bugs may encounter a new pathogen that they can biologically amplify or mechanically spread. Africa is now in the midst of an Ebola epidemic. Ebola is spread by touching an infected human or touching their belongings or surroundings. Ebola persists in the environment for 14-50 days at 4°C (35°F) (Bibby et al. 2014). If bed bugs can pick up Chagas and hepatitis B pathogens by feeding, they can probably pick up the Ebola virus. If they can carry *Staphylcoccus* on their bodies from human skin, they can probably pick up the Ebola virus by crawling on infected humans. So bed bugs can probably carry Ebola. Whether or not they can transmit Ebola depends on the amount of virus needed to cause infection from skin contact, whether bed bugs can incubate the virus and transmit by feeding, and whether or not the bed bug immune system is able to destroy the virus.

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2013 ESA Conference Notes

By Joel Grossman

These Conference Highlights are from the Nov. 10-13, 2013, Entomological Society of America (ESA) annual meeting in Austin, Texas. ESA's next annual meeting is November 15-18. 2015, in Minneapolis, MN. For more information contact the ESA (3 Park Place, Suite 307, Annapolis, MD 21401; 301/731-4535; http://www.entsoc.org

Asian Citrus Psyllid Biocontrol

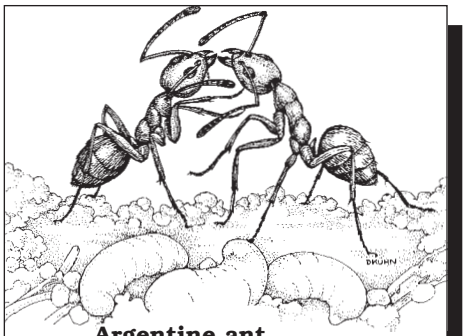
"*Tamarixia radiata* (Eulophidae), a species specific ectoparasitoid of the Asian citrus psyllid (ACP), *Diaphorina citri*, was imported from Pakistan and permitted by the PPQ Permitting Unit for field release in Texas," said Daniel Flores (USDA Mission Lab, 22675 N. Moorefield Rd, Edinburg, TX 78451; daniel.flores@aphis.usda.gov). Since September 2011, over 860,000 parasitoids have been mass-produced and released in the Lower Rio Grande Valley of Texas as well as along the Mexico border. Of these, over 330,000 have been released within a 5-mile (8-km) radius of where citrus greening disease was detected in San Juan, TX, in January 2012.

"Closed cage releases made in fine-mesh sleeve cages indicate parasitism levels at 10.4%," said Flores. When compared to the controls, host mortality is reported at 64.9% in cages with parasitoids present versus 4.4% in cages with parasitoids absent...Host mortality (64.9%) and parasitism rates (10.4%) combined can reduce ACP populations by 75.3%.

Black Cutworm Biocontrol

The black cutworm, *Agrotis ipsilon*, is a pest on South Korea's East Valley golf course as well as turf, field crops and vegetables worldwide, said Chae Min Lee (Kyungpook National Univ, Sangju, South Korea 742-711; llbeloved@hanmail.net). The Korean entomopathogenic nematode, *Steinernema carpocapsae* GSN1 strain, was initially sprayed on pots of ryegrass, bentgrass and zoysiagrass infested with black cutworm.

"Efficacy was higher against 4th instar than 2nd instar of black cutworm in pot and higher on bentgrass than zoysiagrass," said Lee. In ryegrass pots, 2000 infective juveniles (IJs) of *S. carpocapsae* GSN1 provided almost 100% mortality of 2nd and 4th instar black cutworm larvae; 1000 IJs was nearly as effective. Nematode biocontrol sprays in potted ryegrass and zoysiagrass were competitive with neem oil, clothianidin and fenitrothion.



Argentine ant, *Linepithema humile*

Drawing by Diane Kuhn

In golf course field tests on bentgrass greens, *S. carpocapsae* GSN1 provided 85.7% biocontrol of black cutworm.

Cat Thyme Repels Insects

Essential oils like those from catnip were shown to be repellent by Joel Coats et al., said Kamlesh Chauhan (USDA-ARS, Bldg 007 BARC-West, 10300 Baltimore Blvd, Beltsville, MD, 20705; kamal.chauhan@ars.usda.gov). Catnip analogues such as nepetalactam also work well (Chauhan 2005). Continued research led to cat thyme,*Tecurein marum*, an expensive but nonetheless excellent mosquito repellent. In March 2013, a patent was filed for cat thyme lactones (1-2%) as a fragrance and repellent natural product.

When a leaf of cat thyme or catnip is placed over a sucrose source, ants and cockroaches are repelled. Cat thyme iridolactones tend to be very stable, long-lasting molecules. Solvent extraction is used to obtain 1% cat thyme lactones that are long-lasting, knockdown insects well, and deter mosquitoes.

Sunn Hemp and Fall Armyworm

Florida cover crops such as sorghum-sudan grass can be heavily infested with fall armyworm (FAW), *Spodoptera frugiperda*, said Robert Meagher (USDA-ARS-CMAVE, 1600 SW 23rd Dr, Gainesville, FL 32608; Rob.Meagher@ars.usda.gov). Before anticipated fall armyworm moth flights, different cover crops less attractive to fall armyworm might be planted areawide instead of sorghum-sudan grass.

Sunn hemp, *Crotalaria juncea*, is a high biomass legume that can be cut for hay or used as a green manure; seed is readily available from Hawaii and South Africa. Cowpea, another legume, is intermediate in cost. FAW ignores both sunn hemp and cowpea, which is good. Corn planted with sorghum-sudan grass gets the most FAW.

Sunn hemp, with its abundance of bees and predators, seems like a good areawide cover crop choice to reduce FAW populations in corn.

Boric Acid Bait Stops Crazy Ants

Sometime between 1915 and 1935, yellow crazy ant, *Anoplolepis gracilipes*, super-colonies (multiple queens; many hectares) invaded Easter Island, displacing native wildlife, said Philip Stewart (Univ of Queensland, Brisbane St Lucia, QLD 407, Australia; pstewart3@uq.edu.au). The Christmas Island pipistrelle bat, *Pipistrellus murrayi*, entirely vanished from the island in 2009, because the crazy ants eliminated its insect food sources. A

Conference Notes

2009/2010 aerial and hand baiting program with fipronil was replaced in 2010/2011 with a more environmentally friendly boric acid baiting program.

Disodium octaborate tetrahydrate (DOT) in a solution mimicking insect honeydew was placed in bait stations housed in wire cages to keep out lizards, robber crabs, and other non-target creatures. High-density crazy ant super-colonies collapsed to zero in 36 days. The boric acid bait knockdown of the yellow crazy ants allowed natives like the red crab, *Gecarcoidea natalis*, to return. So far, Christmas Island Phosphates has provided about $1 million in funding.

Pheromone Assisted Argentine Ant IPM

Finding trails of the Argentine ant, *Linepithema humile*, is time-consuming and expensive for PCOs, making pheromone trail disruption techniques difficult to use in IPM programs, said Dong-Hwan Choe (Univ of California, 3401 Watkins Dr, Riverside, CA 92521; donghwan.choe@ucr.edu). But limits on pesticide treatments and runoff necessitate more accurate targeting of chemicals to reach ants without polluting the environment. Hence, a pheromone-assisted attract-and-kill technique was developed.

The ant trail pheromone, (Z)-9-hexadecenal, in microgram quantities can be used to attract or divert Argentine ants from trails and nest entrances to bait stations with reduced quantities (milligrams) of insecticides such as fipronil. "The physicochemical characteristics of the pheromone formulation are important factors in improving the persistence of its effect," said Choe.

In Oceanside, CA near a nesting habitat of the endangered California least tern, Argentine ants threatening chicks were attracted to "virtual" bait stations. PVC pipe was treated on the inside with fipronil, a delayed toxicity compound; and a capped inverted bottle of 25% sucrose solution was buried in the sand. Foraging ants crossed the treated surface, picking up the fipronil on the way to consume the sucrose solution.

Mexfly 2-Component Lure

"The Mexican fruit fly (MFF), *Anastrepha ludens*, is a pest species of economic importance with the potential to cause millions of dollars in damage to citrus and other fruit," said David Bartels (USDA-APHIS, 22675 N. Moorefield Rd, Edinburg, TX 78541; david.w.bartels@aphis.usda.gov). A ten week field study (1 March - 10 May, 2013) was conducted to evaluate the effectiveness of bait stations with GF-120 fruit fly bait (with spinosad) imbedded in a wax matrix to control MFF.

"Bait stations (McPhail-like multi-lure traps) contain a two-component lure (Suterra brand) consisting of putresine and ammonium acetate to attract adult MFF," said Bartels. Bait trap MFF mortality was over 90% after a week; versus under 10% for controls.

Bait stations may be especially useful in residential door yards where fruit often remains on the trees year around and as a tool for organic growers.

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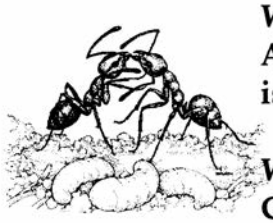

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