MANAGING INSECTICIDE RESISTANCE IN URBAN INSECTS

M. K. RUST
Department of Entomology, University of California, Riverside, CA, USA

INTRODUCTION

Failure to provide control of urban insect pests with conventional insecticide treatments is often attributed to insecticide resistance. In many cases, the failure to properly identify the pest, apply the insecticide or select the correct insecticide or formulation may actually be the problem. In a growing number of documented cases, the development of insecticide resistance has contributed to control failures. The list of pests associated with urban environments that have developed resistance to one or more categories of insecticides is impressive. Among them, resistance to multiple categories of insecticides is widespread in the German cockroach, *Blattella germanica*; housefly, *Musca domestica*; and the yellow fever mosquito, *Aedes aeygpti*. In some species, such as the cat flea, *Ctenocephalides felis*, broad spectrum resistance has been documented, but its impact on control is unknown. Among other insects such as flour beetles, *Tribolium spp.*, and dermestids resistance may be confined to just a few categories of insecticides. Resistance has not been demonstrated among social insects such as ants, wasps, and termites.

The development of insecticide resistance can be directly associated with genetic, biological, and ecological factors and to operational practices used to control them (Table 1). The genetic factors that influence the development of resistance are probably beyond the control of most pest management programs. However, certain biological or ecological factors, especially those dealing with movement and untreated refugia, may be exploited to reduce the likelihood of resistance. Of all of the factors influencing the development of resistance, the pest management specialist has the most control over the operational aspects.

Three strategies for managing insecticide resistance have been proposed and implemented with varying levels of success. Proponents of management by moderation recommend tactics that result in low selection pressure and conservation of susceptible insects. Alternative technologies such as heat and modified atmospheres and non-chemical control methodologies can play an important role in management by moderation. Management by saturation proposes an aggressive approach by eliminating the presumably selective advantage of resistance. Pheromones or other semiochemicals, synergists and improved formulations are important elements in such a strategy. The third strategy, management by multiple attack, uses mixtures or rotations of different categories of insecticides or the use of insecticides that have several modes of action. Selection of the proper insecticides is of utmost importance. Factors such as previous exposure histories and the mechanism of resistance may affect the selection process.

Management of resistance by moderation involves techniques that will apply low selection pressure and conserve the susceptible genes within the population. Possible tactics include applying low dosages of insecticides, less frequent applications, or localized treatments, leaving some generations or sites untreated, and using chemicals of short environmental persistence (Georghiou, 1994). In many urban situations, it is likely these tactics or a strategy of moderation will be unacceptable because there is an extremely low pest threshold tolerance and the pests are of a medical or veterinary importance or causing significant damage. In these cases, the use of alternative technologies and strategies such as physical or structural modifications, built-in pest control, anoxia, cold, and heat may be extremely useful tools in combating the development of insecticide resistance. To the best of our knowledge these alternative treatments and technology will kill or mitigate both susceptible and resistant insects.

Proceedings of the Second International Conference on Urban Pests.
K.B. Wildey (editor). 1996

Table 1. Potential factors influencing the selection of resistance to insecticides (Georghiou, 1983).

A. Genetic
1. Frequency of R alleles
2. Number of R alleles
3. Dominance of R alleles
4. Penetrance; expressivity; interactions of R alleles
5. Past selection by other chemicals
6. Extent of integration of R genome with fitness factors

B. Biological
1. Biotic
   a. Generation turn-over
   b. Offspring per generation
   c. Monogamy/polygamy; parthenogenesis
2. Behavioral
   a. Isolation; mobility; migration
   b. Monophagy/polyphagy
   c. Fortuitous survival; refugia

C. Operational
1. The chemical
   a. Chemical nature of pesticide
   b. Relationship to earlier used chemicals
   c. Persistence of residues; formulations
2. The application
   a. Application threshold
   b. Selection threshold
   c. Life stage(s) selected
   d. Mode of application
   e. Space-limited selection
   f. Alternating selection

ALTERNATIVE STRATEGIES TO MANAGE RESISTANCE

Physical or Sructural Modifications

Physical alteration of the structures or the environment can prevent access to structures or eliminate harborage and breeding sites of pests. For decades many different physical control methods have been recommended including the use of screens, caulking and sealing cracks and crevices in structures, and air vents to decrease moisture. Some recent examples are the use of polystyrene beads to reduce potential breeding sites for *Culex quinquefasciatus* in India and *Culex pipiens* in Egypt (Curtis, 1993). The treatment of bednets with pyrethroids can also provide successful and cost effective protection from mosquitoes (Curtis, 1993). These innovative techniques equally prevent resistant and susceptible individuals from developing or gaining access to blood meals.

Barriers consisting of soil particles of specific sizes prevent many species of subterranean termites from tunneling and gaining access to structures (Ebeling and Pence, 1957; Tamshiro *et al*, 1987). Su and Scheffrahn (1992) found that two-sized particle barriers of 2.00–2.36 mm and 2.36–2.80 mm prevented *Coptotermes formosanus* and *Reticulitermes flavipes* from penetrating soil barriers. Another type of physical barrier involves the use of stainless steel screen which has also been effective in preventing subterranean termites from gaining access to structures (Lenz and Runko, 1994). The screen contains about 15 strands per cm of a high-alloy stainless steel. Even though insecticide resistance has not been demonstrated in subterranean termites, these physical barriers are excellent additional tools in reducing the amount of insecticide applied to the urban environment and need to be incorporated into urban IPM.

Built-in Pest Control

The concept of "built-in" pest control was first proposed by Ebeling and co-workers in the early 1960's (review by Ebeling, 1995). Inorganic dusts such as silica aerogel and boric acid were applied during construction of buildings to eliminate harborage and breeding sites for insects such as drywood termites, carpet beetles, and cockroaches (Ebeling and Wagner, 1964 a, b; Ebeling *et al*, 1977). This concept was expanded to treating existing infestations of cockroaches (Ebeling and Wagner, 1964 b, c, d). Certain dusts such as Dri-Die™ and Cab-O-Sil M5 remove the insect's cuticular wax layer resulting in desiccation whereas boric acid is toxic on ingestion or contact with the insect's cuticle (Ebeling *et al*, 1975). Recent studies by Cochran (1995) found that boric acid will disrupt the midgut epithelium. The use of boric acid to treat wall voids and harborages has been an extremely successful tool in combating resistance in *B. germanica* (Ebeling and Wagner, 1964 c; Slater *et al*, 1979; Reierson *et al*, 1988). A combination of treatments including built-in pest control reduced the number of yearly treatments by 40%.

To date, there have not been any reports of resistance to inorganic desiccants and boric acid. The development of resistance to boric acid may be unlikely because of its various routes of entry into the insect's body and several possible modes of action (Ebeling *et al*, 1975). Interestingly, Klotz and Moss (1994) have shown that the activity of boric acid baits may be synergized thus reducing the concentrations required to produce kill. Their findings may lead to improved baits for cockroaches and ants.

Use of Extreme Temperatures

Exposure to cold temperatures has been used to control pests of fabrics and stored food products since the 1930's. However, certain insects such as the rusty grain beetle, *Cryptolestes ferrugineus*, can survive exposures to cold after periods of acclimatization. *C. ferrugineus* survived exposures to −12°C after a 4–week acclimation at 15°C (Smith, 1970). Fortunately, museum pests such as *Tineola bisselliella*, *Blattella germanica*, and *Blatta orientalis* only increased their cold tolerance a few degrees after periods of cold acclimation and consequently can be killed by modern refrigeration (Solomon and Adamson, 1955). In general, most stored-product insects and mites are killed within minutes at −20°C (Fields, 1992). Cold exposures have also been widely used by museum curators to treat infested objects and materials. Continuous exposures at −20°C for 2–3 weeks are generally lethal to all life stages of carpet beetles, dermestids, clothes moths, and other museum pests (review by Strang, 1992). As temperatures approach 0°C, the time required to kill many species increases to 50 days. One of the disadvantages with this technique, however, is that the materials may be damaged if they are not carefully placed in the freezers during treatments.

Liquid nitrogen has been used to rapidly lower the temperatures of wood infested with termites and beetles (Forbes and Ebeling, 1986) and this process is currently used in a commercial process in California. The minimum lethal temperatures required to provide 100% kill of drywood termites and several stages of lyctid powderpost beetles was determined by decreasing the temperature 1°C/min and removing insects at predetermined temperatures (Fig. 1).

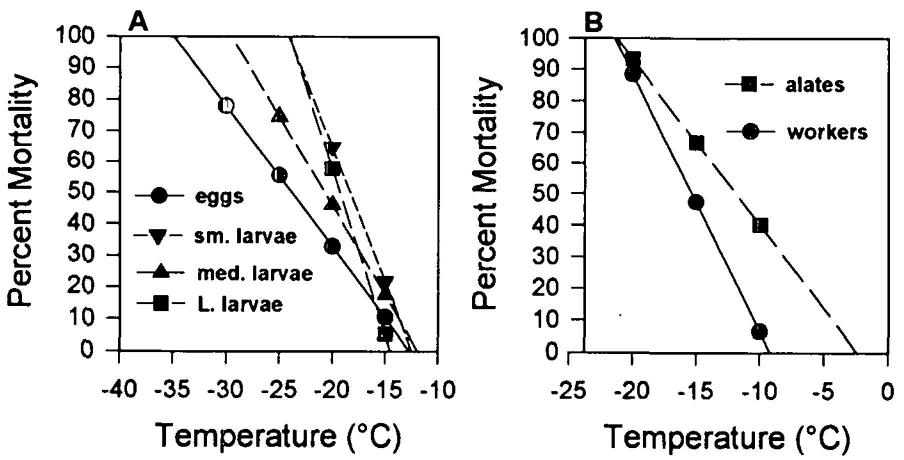

Figure 1. The minimum lethal temperature required to kill immature stages of *Lyctus brunneus* (A) and *Incisitermes minor* (B).

Even though many insects are capable of adating to and surviving exposure to cold temperatures, very short exposures to temperatures above 48.8°C (120°F) are lethal. The minimum exposure period required to kill several different urban pests are shown in Table 2. In structures, this temperature is achieved from air driven by an electrically driven blower through a gas-fired heater (Forbes and Ebeling, 1987). It typically takes 6 hours for the sill plate resting on concrete to reach 49°C. This process is currently being used by a number of pest control companies and military to control termites and cockroaches.

Interestingly, Ebeling (1990) found that heat will synergize the activity of boric acid against German cockroaches. An 80-minute exposure at 43.3°C (110°F) killed 100% of *B. germanica* within 48 hours whereas the heat alone killed only 60% and boric acid only 40%. Ebeling (1995) suggests that the heat-sensitive molecular structure of the cuticle may be disrupted establishing an aqueous continuum enhancing the penetration of boric acid. The use of boric acid applied to wall, cabinet and ceiling voids and heat may be an attractive treatment in large food handling establishments where it may be difficult to maintain temperatures above 48.8°C for 60 minutes.

Modified Atmospheres

The use of modified atmospheres using carbon dioxide generated from dry ice or compressed gas cylinders has been used to kill German cockroaches (Barnhart 1963; Cantwell *et al*, 1973). This process has also been widely recommended for the control of stored product pests, especially where small amounts of food materials are infested.

In recent years, there has been an increased interest in the use of low oxygen atmospheres to control pests of museums, archives, and libraries (Valentin and Preusser, 1990). Gilberg (1989) provided 100% kill of *Tineola bisselliella*, *Lasioderma serricorne*, *Stegobium paniceum*, *Lytcus brunneus*, and *Anthrenus vorax* exposed for 1–3 weeks in 0.4% O_2 atmospheres. Rust and Kennedy (1992) were able to kill 12 different museum pests in chambers purged with nitrogen to produce 0.1% O_2 atmospheres. The time required to produce 100% kill varied with each species and life stage (Rust *et al*, 1996). Factors that influence the exposure time include the oxygen concentration, temperature, and relative humidity. Objects can be enclosed in bags made of Aclar, Saran or mylar that are impermeable to oxygen (Burke, 1992). To reduce the oxygen concentration, packets of Ageless™ oxygen scavenger are placed inside the bag (Daniel and Lambert, 1993). The ability to create customized bags and the use of Ageless™ to remove oxygen provides a tremendous amount of flexibility in treating infested objects and materials.

CONCLUSIONS

To successfully manage insecticide resistance in insects of urban importance, it is necessary to consider the social and medical importance of the urban pest and to integrate the biology and ecology of the pest with the proposed control strategies. The ability to constantly monitor the pest population and the resistance levels as they relate to changes of susceptibility to the methodology

Table 2. The minimum exposure time required to kill various urban pests held at 49% RH.

		Exposure (min) required to produce 100% kill[a]				
Species	Common name	40.6°C	43.3°C	46.1°C	48.9°C	51.7°C
Blattella germanica	German cockroach				60	
Incisitermes minor	Western drywood termite			120	45	15
Reticulitermes hesperus	Western subterranean termite	60	30	30		
Camponotus vicinus	Carpenter ant			120	45	

[a]Heated in chambers maintained at 49% RH.

of control is essential. Control procedures involving management by moderation should be used whenever possible. The success or failure of urban IPM programs and resistance management programs depends on the decision maker, the pest control personnel or the public. Those decisions must be based on the best possible scientific information available. Clearly, additional research is needed to provide this critical information for most urban pest species.

REFERENCES

Barnhart, C. S. (1963). How to control cockroaches with dry fumigation. *Pest Contr.* 31: 30.

Burke, J. (1992). Vapor barrier films. *WAAC Newsletter* 14: 13–17.

Cantwell, G. E., Tompkins, G. J., and Watson, P. N. (1973). Control of German cockroach with carbon dioxide. *Pest Contr. 41*: 40, 42, 48.

Cochran, D. G. (1995). Toxic effects of boric acid on the German cockroach. *Experientia* 51: 561–563.

Curtis, C. F. (1993). Alternatives to conventional insecticides for urban vector and pest control, pp. 25–29. *In* Proceedings of the 1st International Conference on Insect Pests in the Urban Environment. St. John's College, Cambridge. BPCC Wheatons Ltd., Exter.

Daniel, V., and Lambert, F. L. (1993). Ageless™ Oxygen scavenger: practical applications. *WAAC Newsletter* 15: 12–14.

Ebeling, W. (1995). Inorganic insecticides and dusts, pp. 193–230. *In* M. K. Rust, J. M. Owens, D. A. Reierson (eds.), Understanding and controlling the German cockroach. Oxford University Press, New York.

Ebeling, W., and Pence, R. J. (1957). Relation of particle size to the penetration of subterranean termites through barriers of sand or cinders. *J. Econ. Entomol.* 50: 690–692.

Ebeling, W., Reierson, D. A., Pence, R. J., and Viray, M. S. (1975). Silica aerogel, and boric acid against cockroaches.: external and internal action. *Pest. Biochem.* 5: 81–89.

Ebeling, W., and Wagner, R. E. (1964a). Built-in pest control. *Cal. Ag.* 18: 8–12.

Ebeling, W., and Wagner, R. E. (1964b). Built-in pest control. *Pest Contr.* 32: 20–22,24,26,28,31,32.

Ebeling, W., and Wagner, R. E. (1964c). The experiences of public housing projects in the control of cockroaches with Dri-Die or Dri-Die plus toxicants. Pest Control Review Univ. Calif. Ag. Ext. Serv. p. 1–6.

Ebeling, W., and Wagner, R. E. (1964d). The treatment of voids under cabinets. *P.C.O. News* 24: 8–11.

Ebeling, W., Wagner, R. E, and Reierson, D. A. (1977). Cockroach proofing at the time of construction, pp. 33–37. *In* Proceedings of the 1977 seminar on cockroach control. New York Dept. Public Health, Albany, New York.

Fields, P. G. (1992). The control of stored-product insects and mites with extreme temperatures. *J. Stored Prod.* 28: 89–118.

Forbes, C., and Ebeling, W. (1986). Update: liquid nitrogen controls drywood termites. *The IPM Practitioner* 8: 1–1–3.

Forbes, C., and Ebeling, W. (1987). Update: use of heat for the elimination of structural pests. *The IPM Practitioner* 9: 1–6.

Georghiou, G. P. (1983). Management of resistance in arthropods, pp. 769–792. *In* G. P. Georghiou and T. Saito (eds.), Pest resistance to pesticides. Plenum, New York.

Georghiou, C. P. (1994). Principles of insecticide resistance management. *Phytoprotection* 75: 51–59.

Klotz, J., and Moss, J. M. (1994). Renewed interest in an ancient compound. *Pest Contr. Tech.* 22:55, 58.

Lenz, M, and Runko, S. (1994). Protections of buildings, other structures and materials in ground contact from attack by subterranean termites (Isoptera) with a physical barrier - a fine mesh of high grade stainless steel. *Sociobiology* 24: 1–16.

Reierson, D. A., Rust, M. K., Slater, A. J., and Slater, T. M. (1988). Insecticide resistance affects cockroach control. *Cal. Ag.* 18–20

Rust, M. K., Kennedy, J. M., Daniel, V., Druzik, J. R., and Preusser, F. D. (1996). The feasibility of using modified atmospheres to control insect pests in museums. *Studies in Conservation.* (in press)

Slater, A. J., McIntosh, L., Coleman, R. B., and Hurlbert, M. (1979). German cockroach management in student housing. *J. Envirn. Health*: 42: 21–24.

Smith, L. E. (1970). Effects of cold acclimation on supercooling and survival of the rusty grain beetle, Cryptolestes ferrugineus (Stephens) (Coleoptera: Cucujidae) at subzero temperatures. *Canadian J. Zool.* 48: 853–58.

Solomon, M. E., and Adamson, B. E. (1955). The powers of survival of storage and domestic pests under winter conditions in Britain. *Bull. Ent. Res.* 46: 311–355.

Strang, T. J. K. (1992). A review of published temperatures for the control of pest insects in museums. *Collection Forum* 8: 41–67.

Su, N.-Y., and Scheffrahn, R. H. (1992). Penetration of sized-particle barriers by field populations of subterranean termites (Isoptera: Rhinotermitidae). *J. Econ. Entomol.* 85: 2275–2278.

Tamashiro, M., Yates, J. R., and Ebesu, R. H. (1987). The Formosan subterranean termite Hawaii: problems and control, pp. 15–22. *In* M. Tamashiro and N.-Y. Su (eds.), Biology and control of the Formosan subterranean termite. College of Tropical Agriculture and Human Resources, Univ. Hawaii, Honolulu.

Valentin, N., and Preusser, F. (1990). Insect control by inert gases in museums, archives and libraries. *Restaurator* 11: 22–33.