INCREASED DOSAGE (SATURATION) TO OVERCOME POOR CONTROL ASSOCIATED WITH INSECTICIDE RESISTANCE IN URBAN INSECT PESTS

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Poor control of urban insects, especially cockroaches, mosquitoes and flies is often associated with insecticide resistance. Resistance among cockroaches is geographically widespread as is often symptomatic at significant levels to a variety of insecticides. Resistance appears to be more important in cockroach control failures than is misapplication of insecticide by pest control practitioners. Of mechanisms involved in resistance, metabolism and target site insensitivity are most important, and those mechanisms may be affected by reduced rate of penetration of active ingredient through cuticle. Intrinsic and learned avoidance behaviours may also be selected from insecticide exposure and result in potentiation of resistance mechanisms.

Using the German cockroach, *Blattella germanica* (L.), as a model, we investigated resultant effects of resistance management by saturation. Topical (1 µl) LD values indicate that moderate levels of resistance to organophosphate insecticides of approximately 6 to 10-fold are common, and pyrethroid resistance ratios (RR) sometimes exceed 100 (Reierson and Rust, 1992). Carbamate insecticides are no longer widely used in the United States for cockroach control, but our recent measured RR for carbamates for some strains exceeds 100. Although disclaimed by some, we have detected low to moderate levels of resistance (RR = <10) to hydramethylnon and abamectin among field-collected *B. germanica*. Coupled with aversive behaviours, even low RR results in poor control (Rust et al 1993). Cockroaches receiving sublethal doses may avoid further contact with the insecticide even though the insecticide remains highly biologically active.

Under some conditions saturation of target insect defenses may improve control. High target-directed doses may overwhelm resistance mechanisms, especially during early stages of resistance development when resistance genes are rare. Microencapsulation, dusts, surface-active agents such as wettable powders, and baits are formulations which potentially deliver high rates of active ingredient and may be useful in a saturation treatment program. Operationally, mechanically removing extraneous insects (e.g. by vacuuming), direct contact spraying, and very thorough application may also overwhelm the remaining target insects, thereby essentially overdosing them. Depending on the situation, in instances where only a few molecules are needed for kill, thorough coverage with high doses of exceptional actives such as pyrethroids, abamectin, fungi, or nematode toxins may be effective even if the RR is high. Delivery technology such as FM and WP may mask high doses so that resistance mechanisms in a high proportion of the population become saturated as the target insects encounter them. Inorganic insecticides such as boric acid and silica gel dusts detour resistance mechanisms by affecting entire organ systems rather than specific target sites. We have achieved >99% control of *B. germanica* with boric acid in field situations where previous application of a much more active pyrethroid insecticide provided <60% suppression because of high levels of insecticide resistance.

In theory, bait is a particularly effective delivery system for managing cockroach resistance by saturation. Attractants, feeding stimulants, and inclusion of particularly enticing food components hypothetically increase the likelihood of overdose, especially if more than a lethal quantity of active ingredient is ingested in a single feeding bout. Probability for survival increases if more than one feeding bout is needed to deliver a lethal dose. Cockroaches that consume a sublethal dose may not return for more. Provided there is minimal aversion before a lethal amount is consumed (Silverman and Bieman, 1993), baits appear to be a good way to deliver a high dose to cockroaches.

Several factors may mediate resistance management by saturation or by nearly any other means (Cochran, 1995). Unfortunately, only a few of the mediating factors may be effectively

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manipulated by pest control practitioners. Most of the factors are dynamic and interdependent. They include, but are not limited to the following:

Population isolation, accessibility and refugia

Accessible cockroach populations lend themselves to management by saturation. Inaccessible ones do not. In the laboratory, 100% mortality of propoxur-resistant *B. germanica* was achieved with 2% propoxur granular 'bait' when the cockroaches were confined in simple, uncluttered boxes with little competitive food. Only about 50% mortality was achieved when competitive food and additional shelter were made available. Compared with multi-unit housing such as apartments, better cockroach control is almost always reported for free-standing single-family homes. Likelihood of saturation decreases with increasing complexity and inaccessible refugia.

Immigration

Immigration of susceptible individuals into a resistant population reduces resistance gene frequency. However, our experience indicates that because of insecticide use it is unlikely that susceptible individuals immigrate to a significant extent. Resistance management by saturation in the absence of immigration may be highly effective, and may in part account for high levels of control reported in single-family homes. On the other hand, in a study in Los Angeles, significant numbers of *B. germanica* reinfested apartments within 6 months of fumigation with sulfuryl fluoride to control drywood termites. Progeny of cockroaches collected from the apartments were highly resistant to pyrethroid insecticide, indicating immigration of resistant individuals, perhaps from goods brought in from nearby shops and markets. Saturation had little effect on resistance management in this instance.

Insect behaviour

Improved sanitation places stress on *B. germanica*. Removing food increases mobility, thus increasing the likelihood of them coming in contact with well-placed insecticide. Also, cockroaches are much less discerning about food they eat when they are stressed. They will readily consume toxicant-laden bait they would otherwise avoid. Cockroach resistance management by saturation may in some instances need to be coupled with improved sanitation. The long periods of relative immobility of gravid female *B.* germanica make females a particularly difficult stage to attack.

Therefore, creative delivery of increased dosage provides one way to manage insecticide resistance. Saturation may have better utility for some other insects, but resistant cockroaches in certain situations may be controlled or eliminated by providing doses of insecticide which overwhelm the various resistance mechanisms which have been previously selected.

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