Approaches to Biological Control of Termites

by

J. Kenneth Grace[1]

ABSTRACT

Biological control refers to the application or manipulation of predators, parasitoids, or pathogens in order to suppress and manage insect populations. The cryptic habits of subterranean termites limit their susceptibility to predators. Ants are generally considered to be the most effective predators of termites, and under some conditions may be able to exclude them from occupying feeding sites at the soil surface. However, ants are not able to penetrate far into the subterranean gallery system. To date, there is very little documentation of termite parasitism. Thus, the most promising area of biological control research with termites appears to lie with pathogens. Unfortunately, termite social and chemical defenses appear to be strong limiting factors in inhibiting disease outbreaks in termite colonies. Fungi and nematodes have received the greatest attention to date, and a few commercial formulations are either available or on the near horizon, but their field efficacy is not well documented. Bacteria are also currently of interest, and manipulation via molecular techniques may be a viable path to development of efficient microbial agents. Other approaches to enhancing the efficacy of microbial agents may be the use of combinations of pathogens, or insecticide plus pathogen combinations. Microbial control is a balancing act, in that pathogens must not be repellent, and must not have such rapid or dramatic effects upon the infected individuals that others will subsequently avoid contact with them or with the inoculum source. On the other hand, they must be capable of distribution through the colony and induction of either an epizootic or sufficient delayed mortality to essentially destroy the colony. A self-replicating time bomb, akin to a computer virus, would be the ideal microbial control agent.

PREDATORS, PARASITES AND PATHOGENS

Biological control strategies for managing termite (Isoptera) populations have been reviewed by Logan *et al.* (1990), Grace (1997), and Culliney & Grace (2000). Both of the latter two reviews expressed cautious views of the likelihood of true breakthroughs occurring in the

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[1]Dept. of Plant & Environmental Protection Sciences, University of Hawaii at Manoa, 3050 Maile Way, Room 310, Honolulu, Hawaii 96822, USA. E-mail: kennethg@hawaii.edu

use of predators, parasites or pathogens for termite control. Culliney & Grace (2000) concluded that "biological control may yet come to supplement, but is unlikely any time soon to supplant, other established subterranean termite control technologies."

The value of predators or parasites in classical approaches to termite biocontrol does indeed seem to be null. Although chemicals produced by some termite predators may ultimately prove to be of some use (Cornelius et al. 1995, Johnson & Hagen 1981), the cryptic habitat of subterranean termites and their efficient social defenses severally limit the ability of predators to invade the colony and have any significant impact on the termite population. These same factors would also seem to limit parasite success. In fact, with the exception of some phorid flies (cf., Disney 1986), reports of termite parasitism are virtually nonexistent. Intensive collection efforts in southern China by both Chinese and USDA-ARS researchers have not resulted in any records of insect parasitoids affecting the Formosan subterranean termite, *Coptotermes formosanus* Shiraki. This absence of reported parasitism, combined with the observation that *C. formosanus* is considered a severe pest in its native region of southern China, leads to the conclusion that naturally occurring biological control agents are not effective in regulating termite population densities below economic thresholds.

Insect pathogens appear on the surface to hold much greater promise for subterranean termite control; although, as with other biocontrol agents, disease outbreaks have clearly not kept *C. formosanus* or other termite species from becoming economic problems either in native or introduced situations. However, a range of pathogenic organisms have been isolated from termites (cf., Zoberi & Grace 1990b, Zoberi 1995, Osbrink *et al.* 2001), and pathogenicity is not difficult to demonstrate under laboratory conditions. The warm, humid conditions found within a termite nest are conducive to microbial culture, and termite social interactions contributing to pathogen transfer could promote an epizootic within the colony. These factors favoring disease transmission must be balanced, though, against the social or other defenses termites must have developed to permit them to thrive under such conducive conditions.

TERMITE SOCIAL AND CHEMICAL DEFENSES

Rosengaus *et al.* (1998b) have pointed out that the extremely favorable conditions for microbial growth in the termite habitat would lead to pathogens exerting strong selection pressure on the insects. Thus, social behaviors such as allogrooming (Rosengaus *et al.* 1998b, 2000), "head banging" and other means of communicating alarm

(Rosengaus *et al.* 1999a), isolation and burial of infected individuals (Grace & Zoberi 1992), and even strict regulation of caste proportions within the colony (Rosengaus *et al.* 2001) may have developed in whole or in part in response to this selection pressure.

Termites also have developed a number of chemically-mediated defenses against pathogens. At the simplest level, this can mean the ability to detect the toxins produced by pathogenic fungi such as *Metarhizium* and *Beauveria* species, and respond by avoiding contact with fungal spores or toxin-contaminated substrates (Grace 1995). Chemicals produced within the termite nest or gallery system may inhibit microbial growth: Rosengaus *et al.* (1998a) demonstrated that *Zootermopsis angusticollis* Hagen fecal pellets inhibited fungal spore germination, and Chen *et al.* (1998), Wiltz *et al.* (1998), and Wright *et al.* (2000) demonstrated the fungistatic properties of naphthalene and fenchone found in *C. formosanus* nests. Rosengaus *et al.* (1999b) presented evidence of a protective immune response in *Z. angusticollis* nymphs following exposure to bacterial or fungal pathogens. All of these reports are somewhat controversial in terms of the relative importance assigned by the authors to each particular finding. However, it is very clear that termites have developed a number of effective defenses against pathogens, and that epizootics are rare events.

NATURE IS NOT ENOUGH

Biological control is very attractive to researchers, and has proven to be an effective approach to managing many agricultural, and even some structural (cockroach), pests. However, with termites in general, and certainly with *C. formosanus* specifically, the weight of the evidence suggests very strongly that nature is simply not enough. Unless virtually all of the individuals within the termite colony can be directly exposed to an enormous pathogen inoculum load, as when a high concentration of fungal spores is pumped directly into a termite mound, initiation of an epizootic and successful economic control are unlikely. In the laboratory, exposure to active fungal cultures has been found to provide greater control than exposure to spores alone or to extracted fungal toxins (Delate *et al.* 1995, Grace 1995). However, placing a sufficient number of active pathogen cultures in the field for long enough periods to directly expose most of the colony foragers, without contamination or loss of viability of those cultures, is a daunting task.

The use of combinations of different pathogens, or of insecticides plus pathogens, has been proposed as means of overcoming the weaknesses of microbial control (Boucias *et al.* 1996, Ramakrishnan *et al.* 1999, Osbrink *et al.* 2001). However, simultaneous application of multiple microbial control agents would seem to be subject to the same difficulties apparent with maintaining active cultures in the field of a single pathogen, plus additional complications. Boucias *et al.* (1996) demonstrated that sublethal exposures to the nitroguanidine insecticide imidacloprid increased the susceptibility of *Reticulitermes flavipes* (Kollar) to fungal pathogens. This effect appears to be due to the neurotoxic effects of the insecticide reducing termite movement and allogrooming and simply allowing the fungus to grow on the insects more readily, rather than to either suppression of a termite immune response or direct enhancement of fungal growth. Thus, it is not entirely clear whether this should be considered an additive or a synergistic effect.

One has to wonder whether proposed combination treatments may simply be more trouble than they are worth. Although it is true that pathogens grow readily on termites exposed to imidacloprid, for example, it is doubtful that this is of much importance with respect to current methods of using this termiticide, since it is applied at concentrations that are lethal independent of any pathogen exposure. It also seems doubtful that any benefits in terms of health or environmental risk reduction that might be achieved by applying lower sublethal insecticide concentrations and relying upon the presence of naturally occurring pathogens to control the termites would be worth the risk of assuming that these pathogens are universally present and virulent. Applying sublethal insecticide concentrations and artificially cultured pathogens simultaneously, on the other hand, is likely to be much more expensive and complex than simply applying a lethal insecticide concentration alone.

Approaches to biological control that may prove more feasible in the long run than combined pathogen plus pathogen, or insecticide plus pathogen, treatments are (a) genetic modification of microbes to enhance their virulence, and/or (b) interference with the microbial ecology of the termite gut or nest environment. With respect to genetic modification, Grace & Ewart (1996) demonstrated that *C. formosanus* would readily consume recombinant bacteria, and the right combination could produce a lethal "time bomb" for use in termite baits. A better understanding of termite microbial ecology may lead us to new pathogens, or new means of interfering with vital processes (Shelton & Grace 2002). By no means is this a quick route to implementation of novel and economically viable termite control methods, but ongoing microbial survey efforts are gradually providing the necessary foundation (Zoberi & Grace 1990a, Yoshimura 1995, Osbrink *et al.* 2001).

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