Biological Control Strategies for Suppression of Termites[1]

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J. Agric. Entomol. 14(3): 281–289 (July 1997)

ABSTRACT Recent research and progress in developing biological control strategies for termite management are reviewed. Biological control involves the use or manipulation of parasites, predators, or pathogens. There is very little documentation of termite parasitism. Ants are the most important predators of termites, and the interactions of various ant species with termites have recently received a fair amount of research attention. Certain species of ants are effective in excluding termite foragers from localized wood resources, but they are quite limited in their ability to penetrate into subterranean termite galleries in the soil. The greatest potential for biological control of termites appears to lie with insect pathogens, or microbial control. Laboratory studies with insect-pathogenic fungi are particularly promising, although field efficacy data are lacking. The potential advantages of microbial control are such that further research is well justified. However, the technical difficulties that must be overcome are sufficiently daunting that we must temper our enthusiasm with cautious realism.

KEY WORDS Isoptera, *Reticulitermes, Heterotermes, Kalotermes, Coptotermes,* microbial control, entomopathogens

Biological control is generally perceived as both providing more permanent insect control and as having less potential for damage to the environment or to nontarget organisms than chemical pest control interventions, although the latter perception is not without controversy (Howarth 1991). With cryptic insects such as termites (Isoptera), detection prior to the occurrence of significant damage and the effective delivery of insecticides to kill the population or (with subterranean species) to block the path of entry into the threatened structure are particularly challenging. Typically, large quantities of persistent insecticide solutions have been applied to the soil to prevent subterranean termite attack, raising concerns about applicator safety, environmental contamination, and possible deleterious effects on nontarget animals.

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[1] Accepted for publication 19 May 1997.

The use of biological control agents to hunt or to infect termites within their hidden galleries is appealing. The many social interactions within a subterranean termite colony and their maintenance of a dark, damp habitat also would seem to favor survival and distribution of pathogenic microorganisms that could be introduced or encouraged to flourish in microbial control strategies.

This paper represents a selective review of recent research and progress in developing biological control strategies for control of termites. It focuses on termites as pests of urban structures, although recent collaborative efforts between Kenya and Denmark addressing termites of agricultural importance in East and Central Africa (Danish Technological Institute 1992) also are discussed. Thus, this paper should be considered an update on the state of biological termite control, and the reader is referred to the literature citations, and particularly to the review by Logan et al. (1990), for discussions of earlier work in the field.

Parasites of Termites

Biological control may be achieved through the actions of parasites, predators, or pathogens. No insect parasites of termites have yet been reliably documented, although mites considered to be parasitic have been collected from termites (K.L. Strong & J.K. Grace, unpublished data), and phoretic mites are frequently noted by termite researchers (Phillipsen & Coppel 1977, Costa-Leonardo & Soares 1993). However, in laboratory studies with *Reticulitermes flavipes* (Kollar), inoculation of groups of termites with extremely large numbers of phoretic mites proved to have no discernable negative effects on termite feeding or survival (M.H. Zoberi & J.K. Grace, unpublished data).

Predators of Termites

Specialized predators of termites are rather limited in number, possibly because of the cryptic and protected habitats in which termites live. One of the more interesting of these predators, and one deserving of further attention by researchers, is the berothid larva *Lomamyia latipennis* Carpenter that lives within termite nests and was reported to prey upon termite workers by emitting a vapor-phase toxicant (Johnson & Hagen 1981).

More visible specialized predators of nesting and foraging termites include certain ponerine and myrmicine ant species and vertebrates such as aardwolves, aardvarks, and anteaters (Logan et al. 1990). It is extremely doubtful that any of these tropical ant species or large vertebrates could be used in control programs, although the thought of tethering an aardvark in the substructure space beneath an urban dwelling is intriguing.

Opportunistic predation on termites is quite common. During swarming periods, termite alates are readily fed upon by entomophagous arthropods (such as ants and spiders), birds, fish, lizards, geckos, toads, and mammals (including humans). Ants are the most obvious predators of foraging termites, and anecdotal observations of a decline in termite activity within structures associated with Argentine ant, *Linepithema humile* (=*Iridomyrmex humilis*)

(Mayr), infestations are common (c.f., Olkowski & Drlik 1994). In laboratory studies, Wells & Henderson (1993) observed that *Coptotermes formosanus* Shiraki groups with abnormally low soldier proportions were less likely to explore new areas, and that the relatively high proportion of soldiers normally found in colonies of this introduced termite species conferred greater protection from predation by the red imported fire ant, *Solenopsis invicta* Buren, than the smaller number of soldiers typical of native *Reticulitermes* spp. Holmgren colonies in North America. In similar studies with the bigheaded ant, *Pheidole megacephala* (F.), Cornelius & Grace (1997) found that the principal defensive role of termite soldiers was to temporarily prevent ants from invading galleries while the workers sealed breaks in the tunnels and built soil barriers to block further ant invasion.

Ant species commonly found in the urban environment in Hawaii, or collected in termite-infested wood and in traps at field sites, were recently evaluated at the University of Hawaii as potential biological control agents for the Formosan subterranean termite. Behavioral assays with solvent extracts from different ant species established that termite responses to the presence of ants were largely chemically mediated (Cornelius & Grace 1994a). Termites retreated from contact with the dolichoderine ant *Ochetellus glaber* (Mayr) (Cornelius & Grace 1994a, b) due to the repellence of its monoterpene anal gland secretion *cis,trans*- and *trans,cis*-dolichodial (Cornelius et al. 1995). This compound is toxic as well as repellent to termites and may prove to have some value as an insecticide model (Cornelius et al. 1995). However, the strong avoidance behavior exhibited by *C. formosanus* when contacting this ant species, and their subsequent rapid retreat and construction of soil barriers to prevent ants from following (Cornelius & Grace 1995) limit the potential of *O. glaber* as a biological control agent.

In contrast to the semiochemically mediated avoidance of *O. glaber* by termites, chemosensory cues associated with *P. megacephala* stimulate termites to rapidly attack this species (Cornelius & Grace 1994a, 1995, 1996). The bigheaded ant also is more invasive of termite galleries in the soil than *O. glaber*, and *C. formosanus* is forced to retreat further into the soil to construct defensive barriers and suffers greater losses from combat than with *O. glaber* (Cornelius & Grace 1995, 1996, 1997). In practical terms, *P. megacephala* can exclude termites from foraging in a particular location and is more invasive of termite galleries than *O. glaber*, but it also is prone to suffer greater combat casualties than *O. glaber* due to the termites' aggressive response. A more suitable model for a biological control agent is offered by the ant *Tetramorium simillimum* (F. Smith), which did not stimulate a visible response by *C. formosanus* in laboratory assays and was able to cause greater mortality among the unsuspecting termites than either *O. glaber* or *P. megacephala* (Cornelius & Grace 1994a, 1995). However, no interactions of this ant species with termites in Hawaii have yet been observed in the field.

Pathogens of Termites and Microbial Control

The greatest potential for application of biological control to suppression of termite populations appears to lie with pathogenic microorganisms. Certainly, it is this area that has received the most significant research and regulatory (Grace 1994) attention. Nematodes have proven to be extremely virulent in confined conditions in the laboratory (Trudeau 1989) but appear to have a temporary impact on termite foraging activities in the field (Mix 1986, Epsky & Capinera 1988). Although nematode products are currently available in North America for application to the soil to control subterranean termites, the small amount of research published to date indicates that efficacy would be limited to the immediate area of application and quite temporary. Logan et al. (1990) suggested that nematodes might be most efficacious in direct application to small aboveground termite infestations within the branches of high-value crops such as tea bushes.

Only a small amount of research has been reported with either viruses or bacteria as potential termite control agents. Al Fazairy & Hassan (1988) successfully infected the drywood termite *Kalotermes flavicollis* F. with a nuclear polyhedrosis virus isolated from the Egyptian cotton leafworm, *Spodoptera littoralis* (Boisduval), and recently reported the histopathology of the infection in some detail (Al Fazairy & Hassan 1993). Most bacterial research has concentrated on *Bacillus thuringiensis* Berliner (*Bt*), although termites are susceptible in nature to other bacterial infections, such as *Serratia marcescens* Bizio (Khan et al. 1977). Bt is generally considered more of a microbial insecticide than a self-sustaining biological control agent, and recent work by Grace & Ewart (1996) took that approach. These authors investigated the application of the delta-endotoxin of Bt, expressed by a recombinant leaf-colonizing bacterium *Pseudomonas fluorescens* (Trevisan) Migula, and then bio-encapsulated within that killed and fixed bacterium, against Formosan subterranean termites. Neither Lepidoptera nor Coleoptera-active endotoxins proved active against *C. formosanus*, but termites readily consumed large quantities of the genetically engineered bacterium, suggesting that other more termite-active toxins might be encapsulated in this fashion as baits (Grace & Ewart 1996).

Insect-pathogenic fungi have been the major foci of research on microbial control of termites. Such fungi are much less invasive than nematodes, causing fewer immediate physiological and behavioral changes in the insect and killing more slowly. Thus, these pathogens appear to have a greater potential for distribution through social contacts among colony members. The fairly constant temperatures and damp, dark conditions in subterranean termite galleries also favor fungal growth. Currently, collaborative efforts between researchers in Kenya and Denmark are addressing the potential for fungal control of termites in African agriculture (Danish Technological Institute 1992). Recent theses at the Royal Veterinary and Agricultural University, Copenhagen, have reported the isolation of *Cordycepioideus bisporus* Stifler from *Macrotermes subhyalinus* Rambur and laboratory evaluations of strains of *C. bisporus* and *Paecilomyces fumosoroseus* (Wize) Brown and Smith against *M. subhyalinus* (Ochiel 1995) and of the more well-known pathogenic fungi *Metarhizium anisopliae* (Metsch.) Sorokin and *Beauveria bassiana* (Balsamo) against *Macrotermes michaelseni* (Sjöstedt) (Gitonga 1996). Gitonga (1966) also tested the use of fungus-inoculated sawdust and rice grains as termite baits near *M. michaelseni* mounds, as well as inoculating mounds with dry conidia.

However, these treatments were much less effective than the termite mound treatments reported by Fernandes (1991) and colleagues in Brazil, or by Milner et al. (1996) in Australia. It may be necessary to deposit large quantities of conidia within the central portion of the nest to infect and kill the entire termite colony (Gitonga 1996).

In addition to reported success in treating termite mounds directly with conidia of *M. anisopliae*, Milner et al. (1996) also suggest the use of conidial sprays on wood to repel foraging termites. Although no efficacy data have yet been published, it is logical to expect that a similar effect and thus temporary protection of the treated wood would occur from application to termite-infested wood of a *M. anisopliae* conidial formulation recently announced for sale in North America, BioBlast™ Biological Termiticide (EcoScience, New Brunswick, New Jersey) (Quarles 1997). Repellent effects elicited by nonpathogenic fungi also may have some utility in termite control (Grace et al. 1992).

Both *M. anisopliae* and *B. bassiana* have been isolated from termites (Zoberi & Grace 1990b, Zoberi 1995) in North America and Hawaii, and the relative virulence of these and other strains has been established in laboratory screenings (Grace & Zoberi 1992, Jones et al. 1996, Wells et al. 1995). Researchers in Australia (Milner et al. 1996) and Japan (Suzuki 1991, 1996) also have screened large numbers of fungal isolates. It is entirely possible that additional pathogens will be found by more extensive examinations of the microflora and fauna associated with different termite species (Zoberi & Grace 1990a). However, although Rosengaus & Traniello (1993) have suggested that pathogens may have had profound effects on patterns of inbreeding and outbreeding in termites, there is still a distinct absence of documentation of naturally occurring epizootics among termite populations. There is also an absence of field efficacy data from microbial applications, with the exception of treatment of mounds with massive quantities of conidia. Suzuki (1996) attempted field applications of three pathogenic fungi (*M. anisopliae, B. bassiana*, and *P. fumosoroseus*) against *C. formosanus* but could not establish their efficacy.

Delate et al. (1995), Jones et al. (1996), and Grace (1995) have approached control of *C. formosanus* with pathogenic fungi from the standpoint of bait applications. Isolates of *M. anisopliae* and *B. bassiana* were identified that elicited slow mortality but were highly active at low spore concentrations with little variability in termite responses (Jones et al. 1996). Because of the difficulty of infecting a large proportion of a subterranean termite colony (which may contain several million individuals) with conidial "dusts," these researchers isolated a series of 12 cyclic peptides known as destruxins from *M. anisopliae* (Païs et al. 1981), including three novel compounds (Wahlman & Davidson 1993), and evaluated their potential as bait toxicants for *C. formosanus*. Although feeding on concentrations from 1,500 ppm to 3,300 ppm of destruxin A1 or destruxin E resulted in gradual and consistent termite mortality, subsequent choice tests established that both compounds were too repellent to be effective bait toxicants (Grace 1995). Of course, novel bioencapsulation methods (Grace & Ewart 1996) may prove useful in the future to overcome such repellence.

Living fungal cultures offer a distinct advantage in baiting systems by serving as a constant source of inoculum to termite foragers, thus potentially infecting a larger proportion of the colony than would be possible with dust or aerosol applications of conidia. Delate & Grace (1995) established in laboratory assays that *C. formosanus* foragers would investigate fungal cultures grown on agar-coated paper, leading to transfer of conidia and high mortality despite the repellence of isolated conidia and isolation behavior toward infected individuals (Zoberi & Grace 1990b). However, maintenance of a viable living culture of either *M. anisopliae* or *B. bassiana* within termite bait stations in the field is an extremely challenging proposition.

Potential for Biological Termite Control

Ants certainly act naturally to constrain termite foraging activities to some extent. However, the future of biological control interventions with termites clearly lies with pathogenic microorganisms and microbial control. From a technical standpoint, a mobile or readily distributed and possibly self-perpetuating control agent should mean more complete and less labor-intensive termite control. It must be noted, however, that pathogens generally have little or no mobility on their own, and that isolation behavior towards infected individuals can limit their distribution within the colony. Moreover, there is as yet no published evidence of field efficacy with microbial agents except in mounds, and as temporary repellents. So far as bait development is concerned, either repellence or too-rapid termite mortality will lead to avoidance of the inoculation source and greatly limit any colony-wide effects from the pathogen. Other obvious technical issues that are more difficult to address with a biological agent than with an insecticide are those of quality control, shelf life, and field longevity of the product.

On the other hand, a number of ecological, social, political, and economic factors provide strong motivation for developing microbial control methods for termites. A major factor is the low toxicity of insect pathogens to nontarget organisms and people, which translates into reduced hazard to the applicator, the client, and the environment. From the developer and manufacturer's standpoint, biological agents will likely be candidates for streamlined EPA registration procedures. To the applicator, reduced hazard may mean fewer requirements for public notification prior to application and possibly lower insurance and legal costs.

The technical difficulties are daunting, and research in this area must be considered to be highly speculative. Thus, we should be cautious in our enthusiasm and in commitment of resources to such research. However, the potential payoff from development of a successful system of microbial termite control is so substantial, and the laboratory results to date sufficiently promising, that we must continue to explore its feasibility, albeit with realistic expectations.

Acknowledgment

I acknowledge, with gratitude, the contributions of my collaborators and colleagues in research on biological control of termites. I am particularly grateful for the insights of Minoru Tamashiro (University of Hawaii) who recognized the potential of microbial control quite a few years ago and is no less enthusiastic today. Reviews by Gregg Henderson (Louisiana State University) and an anonymous reviewer helped to improve the manuscript. Support for this work has been provided by USDA-ARS Specific Cooperative Agreement 58-6615-4-037. This is Journal Series No.4276 of the Hawaii Institute of Tropical Agriculture and Human Resources.

References Cited

Al Fazairy, A.A. & F.A. Hassan. 1993. Histopathology of termite *Kalotermes flavicollis* Fabr. infected with a nuclear polyhedrosis virus. Insect Sci. Applic. 14: 127–134.

Cornelius, M.L. & J.K. Grace. 1997. Effect of termite soldiers on the foraging behavior of *Coptotermes formosanus* (Isoptera: Rhinotermitidae) in the presence of predatory ants. Sociobiology 29: 247–253.

Cornelius, M.L. & J.K. Grace. 1996. Effect of two ant species (Hymenoptera: Formicidae) on the foraging and survival of the Formosan subterranean termite (Isoptera: Rhinotermitidae). Environ. Entomol. 25: 85–89.

Cornelius, M.L. & J.K. Grace. 1995. Laboratory evaluations of interactions of three ant species with the Formosan subterranean termite (Isoptera: Rhinotermitidae). Sociobiology 26: 291–298.

Cornelius, M.L. & J.K. Grace. 1994a. Behavioral responses of the Formosan subterranean termite (Isoptera: Rhinotermitidae) to semiochemicals of seven ant species. Environ. Entomol. 23: 1524–1528.

________________. **1994b.** Semiochemicals extracted from a dolichoderine ant affects feeding and tunneling behavior of the Formosan subterranean termite (Isoptera: Rhinotermitidae). J. Econ. Entomol. 87: 705–708.

Cornelius, M.L., J.K. Grace, P.W. Ford & B.S. Davidson. 1995. Toxicity and repellence of semiochemicals extracted from a dolichoderine ant (Hymenoptera: Formicidae) to the Formosan subterranean termite (Isoptera: Rhinotermitidae). Environ. Entomol. 24: 1263–1269.

Costa-Leonardo, A.M. & H.X. Soares. 1993. Occurrence of phoretic mites on the subterranean termite *Heterotermes tenuis* (Isoptera, Rhinotermitidae). Sociobiology 23: 63–69.

Danish Technological Institute. 1992. Proceedings of the 1st Regional Workshop on Termite Research and Control, 17–19 August 1992, Nairobi, Kenya, 127 pp.

Delate, K.M., J.K. Grace & C.H.M. Tome. 1995. Potential use of pathogenic fungi in baits to control the Formosan subterranean termite, *Coptotermes formosanus* Shiraki (Isoptera: Rhinotermitidae). J. Appl. Entomol. 119: 429–433.

Epsky, N.D. & J.L. Capinera. 1988. Efficacy of the entomogenous nematode *Steinernema feltiae* against a subterranean termite, *Reticulitermes tibialis* (Isoptera: Rhinotermitidae). J. Econ. Entomol. 81: 21–30.

Fernandes, P.M. 1991. Controle microbiano de *Cornitermes cumulans* (Kollar, 1832) utilizando *Beauveria bassiana* (Bals.) Vuill. e *Metarhizium anisopliae* (Metsch.) Sorok. PhD Dissertation, ESALQ-Univ. de Sao Paulo, Piracicaba, Brazil.

Gitonga, W. 1996. *Metarhizium anisopliae* (Metschnikoff) Sorokin and *Beauveria bassiana* (Balsamo) Vuillemin as potential biological control agents of *Macrotermes michaelseni* (Sjöstedt) (Isoptera: Termitidae) in Kenya. PhD Dissertation, Royal Veterinary and Agricultural Univ., Copenhagen, Denmark, 144 pp. + appendices.

Grace, J.K. 1995. Microbial termite control, pp. 166–167. *In* Proceedings, Hawaii agriculture: Preparing for growth. University of Hawaii, Coll. Tropical Agri. & Human Resources, 182 pp.

________________. **1994.** Protocol for testing the effects of microbial pest control agents on nontarget subterranean termites (Isoptera: Rhinotermitidae). J. Econ. Entomol. 87: 269-274.

Grace, J.K. & D.M. Ewart. 1996. Recombinant cells of *Pseudomonas fluorescens*: a highly palatable encapsulation for delivery of genetically engineered toxins to subterranean termites (Isoptera: Rhinotermitidae). Letters Appl. Microbiol. 23: 183–186.

Grace, J.K., B.S. Goodell, W.E. Jones, V. Chandhoke & J. Jellison. 1992. Evidence for inhibition of termite (Isoptera: Rhinotermitidae) feeding by extracellular metabolites of a wood decay fungus. Proc. Hawaiian Entomol. Soc. 31: 249–252.

Grace, J.K. & M.H. Zoberi. 1992. Experimental evidence for transmission of *Beauveria bassiana* by *Reticulitermes flavipes* workers (Isoptera: Rhinotermitidae). Sociobiology 20: 23–28.

Howarth, F.G. 1991. Environmental impacts of classical biological control. Annu. Rev. Entomol. 36: 485–509.

Johnson, J.B. & K.S. Hagen. 1981. A neuropterous larva uses an allomone to attack termites. Nature 238: 506–507.

Jones, W.E., J.K. Grace & M. Tamashiro. 1996. Virulence of seven isolates of *Beauveria bassiana* and *Metarhizium anisopliae* to *Coptotermes formosanus* (Isoptera: Rhinotermitidae). Environ. Entomol. 25: 481-487.

Khan, K.I., Q. Fazal, R.H. Jafri & M. Ahmad. 1977. Susceptibility of various species of termites to a pathogen, *Serratia marcescens*. Pakistan J. Scient. Res. 29: 46–47.

Logan, J.W.M., R.H. Cowie & T.G. Wood. 1990. Termite (Isoptera) control in agriculture and forestry by non-chemical methods: a review. Bull. Entomol. Res. 80: 309–330.

Milner, R.J., J.A. Staples & M. Lenz. 1996. Options for termite management using the insect pathogenic fungus *Metarhizium anisopliae*. Internat. Res. Group Wood Preserv. Doc. No. IRG/WP 96–10142: 1-5.

Mix, J. 1986. Nematodes flunk again. Pest Control 53: 48–54.

Ochiel, G.R.S. 1995. Biology and bio-control potential of *Cordycepioideus bisporus* Stifler and *Paecilomyces fumosoroseus* (Wize) Brown & Smith on the higher termite *Macrotermes subhyalinus* Rambur in Kenya. PhD Dissertation, Royal Veterinary and Agricultural Univ., Copenhagen, Denmark, 210 pp.

Olkowski, W. & T. Drlik. 1994. Least-toxic pest management for termites. Bio-Integral Resource Center, Berkeley, California, 55 pp. + appendices.

Païs, M., B.C. Das & P. Ferron. 1981. Depsipeptides from *Metarhizium anisopliae*. Phytochemistry 20: 715–723.

Phillipsen, W.J. & H.C. Coppel. 1977. *Histiostoma formosana* sp.n. associated with the Formosan subterranean termite, *Coptotermes formosanus* Shiraki, (Acarina: Anoetidae- Isoptera: Rhinotermitidae). J. Kansas Entomol. Soc. 50: 496–502.

Quarles, W. 1997. New subterranean termite treatments. Common Sense Pest Control 13: 13–19.

Rosengaus, R.B. & J.F.A. Traniello. 1993. Disease risk as a cost of outbreeding in the termite *Zootermopsis angusticollis*. Proc. Natl. Acad. Sci. USA 90: 6641–6645.

Suzuki, K. 1991. Laboratory trials of biological control agents against subterranean termites. Internat. Res. Group Wood Preserv. Doc. No. IRG/WP/1475: 1–11.

Suzuki, K. 1996. Biological control of termites by pathogenic fungi. Proc. Conf. on Forestry and Forest Products Res. (Forest Res. Inst. Malaysia, Kepong, Malaysia) 2: 146–156.

Trudeau, D. 1989. Selection of entomophilic nematodes for control of the eastern subterranean termite, *Reticulitermes flavipes* (Kollar) (Isoptera: Rhinotermitidae). MS Thesis, University of Toronto, Ontario, Canada, 93 pp.

Wahlman, M. & B.S. Davidson. 1993. New destruxins from the entomopathogenic fungus *Metarhizium anisopliae*. J. Nat. Products (Lloydia) 56: 643.

Wells, J.D., J.R. Fuxa & G. Henderson. 1995. Virulence of four fungal pathogens to *Coptotermes formosanus* (Isoptera: Rhinotermitidae). J. Entomol. Sci. 30: 208–215.

Wells, J.D. & G. Henderson. 1993. Fire ant predation on native and introduced subterranean termites in the laboratory: effect of high soldier number in *Coptotermes formosanus*. Ecol. Entomol. 18: 270–274.

Zoberi, M.H. 1995. *Metarhizium anisopliae*, a fungal pathogen of *Reticulitermes flavipes* (Isoptera: Rhinotermitidae). Mycologia 87: 354–359.

Zoberi, M.H. & J.K. Grace. 1990a. Fungi associated with the subterranean termite *Reticulitermes flavipes* (Kollar) in Ontario. Mycologia 82: 289–294.

________________. **1990b.** Isolation of the pathogen *Beauveria bassiana* from *Reticulitermes flavipes* (Isoptera: Rhinotermitidae). Sociobiology 16: 289–296.