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Effect of Entomopathogenic Fungi and Non-repellent Toxicants Fipronil and Imidacloprid Against Termites: A Review

Ambash Riaz and Shahid Raza*

Department of Biotechnology, University of South Asia, Lahore, Pakistan

*Corresponding Author's Email: mianrs@yahoo.com

ABSTRACT: *Non-repellent termiticide such as imidacloprid and fipronil are important to control the subterranean termites. These termiticides effect on the walking and tunneling of subterranean termites in the colony. However, health and environmental concerns related to the use of these termiticide arises question and forced scientific community to focus on alternative, more environmental friendly approaches. Use of microorganisms especially fungi for the control of subterranean termites has gain much attraction in the 40 years as many experimental studies have demonstrated promising output. This method was based on classical biological control with the use of entomopathogenic fungi which can replicate itself in the termite colony and can be transmitted from one individual termite to another, hence creating an epizootic and kill the whole colony. However, lack of positive output in field trial arises concerns about the efficacy of entomopathogenic fungi as a potential approach for the control of subterranean termites. Thus, research on the defense system of subterranean termites against the fungal infection started to gain attention in the past decade, however, interaction between termites and fungi is still poorly understood. This review focuses on the use of non-repellent termiticide to control the subterranean termites, problems arises because of these termiticides, alternative methods for subterranean termite control, biological control of fungi using entomopathogenic fungi and defense mechanism of termites triggered in response to fungal interaction.*

Key words: *Non-repellent termiticides, imidacloprid, fipronil, subterranean termites, entomopathogenic fungi, epizootic.*

INTRODUCTION

Termites are social insects that live in the form of colonies. They can be found worldwide especially in tropical and sub-tropical regions. Termites feed on cellulose, making themselves the greatest enemy of wood. To control their infestation in the wood, man developed many techniques which include bait system, high voltage electric current, chemical and biological control etc. Apart from termites' destructive nature, termites are beneficial insects in some ways. In some countries, they are edible. As they feed cellulose, they decompose the dead trees and increase the fertility of soil (Ibrahim and Adebote, 2012). In world's warmer region such as West Africa, termites are considered an important and common insect. In some area of West Africa, termite occupied a large part of landscape. As they feed on wood, they can cause serious damage to the wood users. Wooden beams, Animal pens and telephone poles become useless because of termites attack. Moreover, they can also cause damage to trees and plants. Often termites are unnoticed to a man but they become obvious mostly during rainy season. When they leave their nest they tend to develop a new colony. Their cryptic nature highlights their ecological and economical importance (Wagner et al., 2008).

In 2008-2009, a surveyed was conducted to study the wood destroying termites by collecting sixteen species in Iran. Only 190 plants were infested by termites out of 1050 plant when examined. Most infestations were observed in provinces of Iran i.e Sistan and Boluchestan. More abundant termite species in these provinces were *Microcerotermes diversus* (Silvestri) and *Anacanthotermesvagans* (Hagen). These species preferably infested on *Tamarix gallica* and *Populus caspica* (Ravan, 2010).

Economic Impact

Many termite-control techniques are used to control the infestation of termites throughout the tropical and subtropical regions of the world where most of the subterranean termites are found. Even though action threshold or tolerance for various urban insects, when compare to the action threshold of agriculture insect, is considered very low in developed countries (Robinson, 1996), control of termites may not cost less economically in the areas where majority of subterranean are found. In rural region of various developing countries, this economical cost usually tolerated because cost to remodel the damaged building is often greater than the cost of application of termites-control methods. However, in the USA, action of single destructive subterranean termite species, for example, Formosan subterranean termite, C. formosanus, can withstand the multimillion dollar industry of termite control. It is true, hence, the tolerance for termites is probably zero in the region of high living standards. The cost of termites control, even though high when compared to usual household pests, is considered much less compared to the cost of a house and the potential damage by termites (Su and Scheffrahn, 1998).

In recent years, situations such as, expansion of urban areas and cost of building have contributed to significant increase in financial expenses because of damage caused by termites and their control in USA (Su and Scheffrahn, 1990). A study analyzed the data of Pinto (1981) which showed economic impact of $1.02 billion caused by termites in the USA (Edwards and Mill, 1986). Another study showed that the cost of the termite control solely based on liquid termiticides may exceed $1.5 billion (Su, 1994). Subterranean termites control considered to cost $1.2 billion which may exceed significantly when repair costs are added (Su and Scheffrahn, 1998).

Chemical Control of Termites

The usage of liquid termiticides for the control of subterranean termites has been a primary method for many decades. Conventionally, the purpose of such method is to develop an incessant chemical barrier which eliminates the threat of subterranean termites entering the building.

Management of termites has majorly dependent on chemical techniques which include baiting, dusting and soil treatment (Lee et al., 2003). Termiticides application of soil develops a chemical barrier to prevent the entrance of termites in the structures and building (Blaske et al., 2003). The techniques have been a famous mode of treatment for the control of subterranean termites for over past 50 years (Su et al., 1997b; Miller 2001; Jones 2003; Ibrahim et al., 2003). Before that, repellent termiticides was the rapid and major mode of technique to eliminate the termites from buildings and structures. Chlordane, a repellent termiticide, was a dominated termiticide in term of termites control for a long period (Appel, 2003) until it was banned in many countries during 1980-2000 because of its impact on environment and health (Yeo and Lee, 2007). Over the past decade or more, non-repellent liquid termiticides, which have delayed toxicity, have supported the dominance of termiticide market in many regions of USA due to their high efficiency and low chances of failure (Anonymous, 2002, Potter, 2004).

Fipronil is a non-repellent termiticide which has developed much interest for the control of termites. It is presently one of the most commonly used termiticide to use in termites management (Saran and Kamble, 2008). Fipronil is a phenylpyrazole which works by stopping the γ -aminobutyricacid-gated chloride channel of nervous system of termites (Cole et al., 1993; Hainzl and Casida, 1996). It is highly lethal to termites, with the $LD_{50,}$ especially for western destructive subterranean termite species such as *Reticulitermes hesperus* (Saran and Rust, 2007). Moreover, not only fipronil is effective killing the termites present at the place where it is applied, it also has an effect on the termites outside the immediate treatment zone. A study analyzes the weakening of the termite activity in control group of termites present about 2m from the treated group in the USA (Wagner, 2003). Another study showed that the activity of eastern subterranean termites slowly decreased in monitoring block located nearly 2m from the fipronil treated termite zone (Ripa et al., 2007).

Beside fipronil, other non-repellent termiticides which used commonly to control termite infestation is imidacloprid. The termiticides falls in the neonicotinoid class of insecticides (Matsuda et al., 2001). It has delayed mode of action against termites (Ramakrishnan et al., 2000; Gahlhoff and Koehler, 2001; Thorne and Breisch, 2001; Haagsma and Rust 2007), and it can transfer from treated termites to new termites in the colony (Haagsma and Rust, 2007). Hence suggesting that I may have effect on the colonies of termites stretching outside of treated zone (Thorne and Breisch, 2001). Studies from field observations showed the mixed situation of potential colony level effect of imidacloprid (Parman and Vargo, 2010).

Biological Control

Termites majorly feed on wood and can damage live trees, agricultural crops and buildings made of woods thus they cause extreme economic loss especially in tropical and sub- tropical areas. To avoid these problems, chemical and physical barriers were used but because of their long persistence in and possible entry in food chain, make scientists to focus on termite biological control methods because these methods are safe and environmental friendly (Sindhu et al., 2011).

Many effective biological control agent against termite species gained much interest of scientific community in this field (Culliney and Grace, 2000). Organisms used to control the termites include; bacteria, viruses, nematodes and especially entomopathogenic fungi. Many experimental studies demonstrated a great promise of using these microorganisms against termites in field trial, however only four researches showed successful field trials and these trials were restricted only to the colonies of arboreal or mound-building species (Hänel and Watson, 1983; Milner and Staples, 1996; Staples and Milner, 2000; Lenz, 2005) in which majority of the pathogenic formulation were gusted into the central part of nest. Factors such as, termite complex tunneling pattern, long foraging distance and their cryptic life cycle, these kind of methods is problematic (King and Spink, 1969; Su and Scheffrahn, 1988).

The use of entomopathogenic fungi against subterranean termites falls in the category of classic biological control (Ferron, 1978; Lacey et al., 2001). The use of biological agent in combination of virulent agent which can self-replicate in termite colonies and transfer from an individual termite to another, hence causing an epizootic and destroy the whole colony, is seems to be an efficient way of control subterranean termites. The possibility of these kind of approaches was based on the assumptions; the environment of soil allow conditions which are highly favorable for nourishing pathogenic infection and supporting epizootic; temperature and humidity in termites colonies and termites social behavior support easy and rapid transmission of pathogens from one individual to another within the colony; and due to self-replication of pathogenic fungi, it id high probable that it will spread and create epizootics in termites colonies. These assumptions were supported by many scientist (Toumanoff and Rombaut, 1965; Kramm et al., 1982; Lai et al., 1982; Hänel and Watson, 1983; McCoy, 1990; Wells et al., 1995; Zoberi, 1995; Delate et al., 1995; Boucias et al., 1996; Jones et al., 1996; Grace, 1997; Rosengaus and Traniello, 1997; Milner et al., 1998b; Culliney and Grace, 2000; Wright et al., 2002; Lax and Osbrink, 2003; Myles, 2002; Chouvenc, 2003; Sun et al., 2003), to the extent that it achieved the ranking of a dogma in the field of termite studies. However, a study reported that no pathogens showed a significant effect on termites in field trials and no researcher has ever challenged this statement as it is almost ironic to reach such agreement about the efficiency of pathogens, when there was no artificial or natural epizootic ever reported in termite biological control field.

Mode of Action

Entomopathogenic fungi attack their hosts by the integument and kill them by producing toxic chemicals and their by-products, weakening of metabolites of host, destroying their major tissue or combination of all three (Yendol and Paschke, 1965; Bao and Yendol, 1971; HaÈnel, 1981). Different studies analyzed the mode of action of different arthropods against entomopathogenic fungal species (Ferron et al.,1991; Boucias and Pendland, 1991). The mechanism of disease development of these fungi in termites seems to be similar to other insects which went through the following steps (Roberts and Humber, 1984):

1. Attachment of fungal conidium on termite cuticle
2. Growth of conidium on the termite
3. Infiltration of cuticle
4. Germination of fungi in the haemocoel
5. Toxin production
6. Death of termite

Many studies contributed to understand the fungi-termite interaction mechanism by studying on different fungal and termite species. Detailed life cycle of *Metarhizium anisopliae* in *Nasutitermes exitiosus* was explained by HaÈnel (1982). Another study demonstrated the action mode of fungi *Coptotermes formosanus* (Leong, 1966). Bao and Yendol (1971) showed the histopathology of infection of *Beauveria bassiana* in *Reticulitermes Xavipes* workers while biochemical and histopathological changes in queen of *Odontotermes obesus* infested with *Aspergillus Xavus* was described by Sannasi (1969a, b). Infection of *Conidiobolus coronata* (Entomophthora coronata) in *Reticulitermes Xavipes* was studied by Yendol and Paschke (1965) in detail.

In some entomopathogenic fungi species, it is also possible that the infection in termites introduced through alimentary canal. It is demonstrated in a study that germination and penetration of *B. bassiana* occurred in the foregut of *Reticulitermes sp*, resulting in the growth of hyphal bodies in the haemocoel (Kramm and West, 1982). However, they were not ablr to demonstrate the infection of M. anisopliae through gut, although both *B. bassiana* and *M. anisopliae* could be recovered from the gut of the Reticulitermes sp. Infection of *B. bassiana* in *R. xavipes* occurred through gut but termites' gut found to be more resistance to fungal infection and its penetration, moreover, fungal spores penetrated in hind-gut and mid-gut were mostly non-viable (Bao and Yendol, 1971). Infection of *C. coronate* in *R. xavipes* does not occur though hind or mid-gut but the esophagus (Yendol and Paschke,1965). Dillon and Charnley (1991) reported that the spores of *B, bassiana* (which was mistakenly cited as spores of *M. anisopliae*) used in Kramm and West (1982) study (the termites were allowed to roam on the cultures of fungi) made the result incorrect and hence, making the findings less significant. Even though, whether fungus can infect the termite species, fungal way of infection through termite gut could create high chances of epizootic potential of pathogenic fungi (Kramm and West, 1982).

Spores of pathogenic fungi may have toxic compound which could kill termites when ingested by them (Gunner et al., 1994). A laboratory experiment showed high mortality rate of *C. formosanus* infected by *Conidiobolus coronatus* in the lab bioassay, was not because of the fungi but some other factors (Wells et al., 1995). Entomopathogenic fungi such as *M. anisopliae* var. anisopliae (Jegorov et al., 1989b; Loutelier et al., 1996), some strains of *M. anisopliae* var. major (Kaijiang and Roberts, 1986), the beauvericins from *B. bassiana* (Jegorov et al., 1989a), and *Aschersonia spp*. (Krasnoff and Gibson, 1996), produce cyclic depsipeptides, including destruxins from *M. anisopliae*, against termites and other insects. on contrary, while depsipeptides are attached on the surface of spores of

Beauveria spp. (Jegorov et al., 1989a), destruxins of Metarhizium spp are usually attached with in vitro or in vivo mycelial growth (Chen et al., 1999).

Defense Mechanisms in Termites

Regardless of laboratory successes, the absence of successful epizootic in termite colonies in field trials proposes that dispersal and transmission of pathogen from one individual termite to another is limited and that some processes within termite colony do not allow pathogen to self-replicate or complete their life cycle. Recent studies have focused on the defense system of termites which involve in disease resistance as many defense systems are reported in case of other social insects (Cremer et al., 2007). These processes include; alarm behavior of termites with in colony (Rosengaus et al., 1999a; Myles, 2002), their grooming behavior (Rosengaus et al., 1998b, Yanagawa and Shimizu, 2007), avoidance of infected corpses (Milner et al., 1998b), internment of infected termite bodies (Jones et al., 1996), necrophagy (Myles, 2002), presence of unpredictable chemicals in the colony (Rosengaus et al., 2000a, 2004), demography of colony (Rosengaus and Traniello, 2001), their immune system (Rosengaus et al., 1999b, 2007; Lamberty et al., 2001; Thompson et al., 2003; Bulmer and Crozier, 2004; Xu et al., 2009), termite defense mechanism achieved by release of antimicrobial chemical by their gut (Rosengaus et al., 1998a), method of interaction with pathogens (Rosengaus et al., 2003), architecture of nest (Pie et al., 2004), and social organization (Traniello et al., 2002). These studies demonstrate important information about termite defense system, however, it is yet to understand the mechanism by which these factors interact with each other in termite nest and it may vary from one termite species to another or the microorganism involved.

CONCLUSION

Effect of non-repellent termiticides such as fipronil and imidacloprid as a potential candidate against termite control has already been established and well documented. Questions arise when it comes to environmental and health concerns associated with the use of termiticides, which make scientist to focus on alternative, more environmental friendly approaches.

Termites are very vulnerable to a wide range of fungal strains especially entomopathogenic fungal isolates, however, the efficiency of these entomopathogenic fungi are restricted be unknown colonial response of termites to the fungal threat. There is an active argument as to whether termites can sense the fungi as a threat to the termite nest. It seems doubtful that infected termite cadavers are removed from the nest or in many circumstances actively concealed or buried. The main debate focused on the termite recognition of fungi as threat to their colony. Some scientists believe that the fungal conidia re repellent and can be used as preventive or barrier to control the termite infestation, other scientists believed that fungal conidia are not repellent but fungus can be used in bait system to control the population of termites. Its seems that the lack of data and research on the termite-fungi interaction, and the difficulty of assessing meaningful researches in labs along with secrecy of termites in field trials, arise these kinds of diverse opinions among research community. Important questions that need immediate focus and critical evaluation are; is the repellent nature of spores of fungi triggered a response sytem in termites or termites can differ the entomopathogenic spores from the spores of non-pathogenic fungi isolates (such as penicillium) or, in this matter, dead spores? If yes, then is there something inherit in the spores of entomopathogenic fungal strain that makes them different from non-pathogenic fungal isolates and help termites to differ them apart and trigger pathogenic alarm response in termites?

The efficacy of pathogenic fungi against termites has yet to be analyzed for better output in the field trial. In USA, there is only fungal based product for sale in the market, using M. anisopliae against termite, however, other countries need year of research to reach that mark or even become acceptable by public. Biological products to control termites are easy to sell in household but consistent efficiency must be shown. Even if these pathogenic fungi do not show successful output consistently in urban areas, there will always fungi based product to control termites as research related to the biological control of termites is becoming more fixated on suppression of colonies of termites, to minimize the damage done by termites and more consistent pest management.

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