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Report

Biological Control as an Alternative Measure for Tarnished Plant Bug Control in Mississippi

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Abstract: Tarnished plant bug (TPB), *Lygus lineolaris* (Palisot de Beauvois), is a common pest of the main agricultural crops in Mississippi, particularly of cotton in the Mississippi Delta. Tarnished Plant Bug in cotton is economically important through reductions of crop yield. Losses may vary depending on TPB population levels, environmental conditions, or efficacy of insecticides. For more than 60 years numerous investigations on TPB control have been conducted based on biology, hosts, and distribution; however, more studies need to be conducted on ecology, behavior, and population dynamics to better understand its control. The experiences gained in the last 30 years of research should be reanalyzed in the context of an optimized Integrated Pest Management (IPM) Program for this insect. New approaches to the management of TPB in Mississippi with a better and broader realization of the vital role of natural control agents in regulation of this insect population are needed.

Keywords: Biological Control, IPM, TPB, *Lygus lineolaris*, parasitoids, predators

Introduction

Tarnished plant bug (TPB) was the only mirid known as a pest throughout the mid-eighteenth century (Riley 1870). Riley (1870) demonstrated its damages and commented “None but the specie under consideration [TPB] has thrust itself upon public notice by its evil doing”. Cook (1876) and Howard (1892) acknowledged that the family Miridae is quite extensive, but only one mirid, TPB, inflicts serious injury. In the late 1800s and early 1900s, when crop monocultures developed in North America, outbreaks of plant bugs certainly occurred. Domek and Scott (1985) mentioned that Lygus bugs, thriving under the conditions of modern agriculture, proved great adaptability to introduced crops and weeds. Robbins et al. (2000) stated that TPB probably has the broadest documented feeding niche of any known arthropod. In cotton, TPB has been considered an early season pest of concern after initiation of flowering (Black 1973, Gaylor et al. 1983, Phelps et al 1997, Scott and Snodgrass 2000, Musser et al. 2007 and 2009). Yield losses depend on population levels, which may vary with environmental conditions and efficacy of insecticides (Leonard and Cook 2007).

More insecticides are used in cotton than any other single crop with nearly $2.6 billion worth of pesticides sprayed on cotton fields each year (Lu et al. 2012). Across the midsouthern states of

Arkansas, Louisiana, and Mississippi during 1991 to 2005, TPB infested 77-99 percent of cotton acreage (Leonard and Cook 2007). During these years, a range of 44 to 93 per cent of infested acres was treated with one or more insecticide applications. Cost of these control strategies increased 10 fold, from $5 million in 1991 to more than $50 million in 2005 (Leonard and Cook 2007).

Due to continuous exposure to the most common insecticides in the Mississippi Delta, TPB has evolved tolerance to the extent that some organophosphates and cyclidine insecticides no longer control population of TPB effectively (Snodgrass 1996, Hollingsworth et al. 1997, Snodgrass and Scott 2002, Snodgrass et al. 2009). Since the late nineties, potential alternatives to conventional pesticides became more important due to the remarkable ability of TPB to develop resistance to pesticides. Increases in insecticide rates became costly to cotton producers, and alarmed the community regarding hazards from insecticide applications. Therefore, numerous investigations have been conducted to investigate effective and acceptable solutions, including biological control (Cohen and Urias 1986, Snodgrass 1991, Snodgrass and Fayad 1991, Cohen and Staten 1994, Cohen and Smith 1998, Cohen 2000, Smith and Nordlund 2000, Williams et al. 2003, Zhu and Williams 2002, Riddick 2003); sterile insect technique (Villavaso 2005); alternate host plant management (Snodgrass and Scott 2002, Snodgrass et al 2006, Lund et al. 2006a, Abel et al. 2007); and microbial control agents (Snodgrass and Elzen 1994, Leland and Snodgrass 2005, Leland 2005, Leland et al. 2005, McGuire et al. 2006, Lund et al. 2006b, Ugine 2012, Portilla et al. 2014b). Despite these studies and many years of research, a solution to this problem has not been implementable in an Integrated Pest Management (IPM) Program for this pest. This paper presents a review of published results on biological control alternatives to managing TPB populations.

Predators and Parasitoids Tarnished Plant Bugs are attacked in the United States by a variety of predators and parasitoids. Ruberson and Williams (2000) reported a total of 39 natural enemies to TPB in North America including 12 native and five exotic parasitoids, and 21 native predators. Mississippi cotton producers are fortunate to have a wide array of those natural biological control agents that play an important role in managing TPB populations. The Insect Control Guide for Agronomic Crops (2014) mentioned that profitable cotton production would not be possible in Mississippi without the help of biological control agents, which include several species of big-eyed bugs, lady beetles, spiders, green lacewings, and minute pirate bugs. *Deraeocoris nebulosus* (Uhler) (Heteroptera: Miridae) could be added to this list. This predator was observed by Snodgrass (1991) in commercial cotton fields in west-central Mississippi, even under heavy insecticide use. Several USDA scientists in Mississippi developed rearing systems that permitted medium and large-scale production of the most common beneficial predator of TPB (Cohen and Urias 1986, Cohen and Staten 1994, Cohen and Smith 1998, Smith and Nordlund 2000). Predators *Orius insidiosus* (Say), *Geocoris punctipes* (Say), and *Chrysoperla* spp. are considered the most potentially valuable ones for TPB and currently are available from commercial sources. However, a cost effective mass rearing system for these predators is limited, since most commercial rearing systems are based on the use of *Sitotroga* spp. or *Ephistia* spp. eggs. There are currently no mass rearing systems in place for any predator of *Lygus* spp. capable of producing the number of insects required for practical use in crops such as cotton.

From those several parasitoids mentioned by Ruberson and Williams (2000), only the egg parasite *Anaphes iole* (Girault), and the nymphal parasites *Leiophron uniformis* (Gahan), *Peristenus pallipes* (Curtis), and *Eristenus pseudopallipes* (Loan) (all Hymenopterans) are thought to be relatively important (Capinera 2001). Southwestern U.S. populations of TPB are able to encapsulate *L. uniformis* eggs; such encapsulation increases 70% in second instar (Debolt 1991). *Leiophron uniformis* females lay fewer eggs in TPB than any other *Lygus* spp. and even in undisturbed weedy fields; do not reach levels found for the western tarnished plant bug (WTPB), *Lygus hesperus* Knight (Snodgrass and Fayad 1991). The native parasitoid *A. iole* has a Nearctic distribution, and is widespread in the United States. In the Mississippi Delta, this parasitoid is uncommon in cotton producing regions (Williams et al. 2003), but has been observed on several native host plants (Snodgrass et al. 1984). Initial studies on toxicity of field insecticide residues to *A. iole* by Williams et al. (2003) indicated that this parasitoid has potential as an inundative biological control for the TPB in cotton in the midsouthern United States. Results suggested that while most insecticides exhibited high acute toxicity to *A. iole*, residues of several compounds decayed rapidly enough to show promise in an augmentative release program. *Anaphes iole* and braconids of the genus *Peristenus* are the most commonly reared native parasitoids. However, research efforts on the development of rearing methods for these parasitoids have not been adequate. .This is in spite of the fact that an effective artificial diet for *Lygus* spp. developed by Cohen (2000) and modified by Portilla et al. (2011) is available, in which millions of eggs, nymphs and adults of *Lygus* spp. can be produced per day. The ability to produce millions of individuals per day should be exploited to develop efficient holding systems for native predators and parasitoids for the TPB. This advantage might help develop programs using native natural agents through either release or conservation. The native egg parasitoid *A. iole* and the native nymphal parasitoid *L. uniformis* might be considered an effective approach to this program. Parasitism rates of these parasitic wasps are highly variable, but under the presence of exotic plants in the habitat *A. iole* and *L. uniformis* can reach 100% and 70%, respectively (Graham et al. 1986, Debolt 1991). Wheeler (2001) mentioned that native parasitoids that have evolved with their mirid hosts appear to have developed search preferences for particular plant species. Therefore, effects of agro-ecosystem heterogeneity on insect population dynamics, dispersal, and habitat selection have important implications for TPB management.

Several species of European parasitoids including *Leiophron schusteri* (Loan), *Peristenus stygicus* (Loan), *P. digoneutis* (Loan), *P. rubricollis* (Thomson), *P nigricarpus* (Szepligeti), and *P. relictus* (Loan) have been introduced into the United States (Ruberson and Williams 2000, Day et al. 2003). *Peristenus digoneutis* and *P. relictus* are the only parasitic wasps established in some states of the northeastern U.S., but they failed to become established below 40° latitude (Tillman and Mulrooney 2000). The USDA introduced *P. digoneutis* in the 1980s for biological control of TPB in alfalfa (Day 1987). Since its establishment in 1984, it has spread from New Jersey into Pennsylvania, New York, and New England achieving levels of parasitism in alfalfa well above those of native parasitoids (Day 1995). To date, the success of these importations has been limited, but parasitism of *P. digoneutis* found in alfalfa should be considered an important characteristic for further research in this region. In general, those studies suggested that availability of large and diverse native enemies and the possibility of acquiring appropriate exotic enemies could make an important contribution to TPB suppression.

Microbiological Agents

Entomopathogens in the genera: *Beauveria, Verticillium, Paecilomyces, Metarhiziu, Mariannaea, Hirsutella*, *Entomophthora,* and *Isaria* have shown high levels of virulence to TPB under controlled laboratory conditions (Liu et al. 2002). Under field conditions, however, just two pathogens have been recorded: *Entomophthora* spp. and *B. bassiana* (Steinkraus 1996, Steinkraus and Tugwell 1997). The most common native pathogen found naturally in North America attacking *Lygus* spp. is *B. bassiana*. Leland and Snodgrass (2005) found a 0.3 per cent natural incidence of *B. bassiana* infection in TPB populations from wild host plants in the Mississippi Delta, while McGuire (2002) reported 10 per cent natural infection on WTPB in California. Currently there are more than 44 commercial formulations containing *B. bassiana* spores as the active ingredient (Wraight et al. 2001, Jaronski 2013) and labeled to control plant bugs (Butt et al. 2006).

Several studies against TPB have been conducted using commercial isolates of *B. bassiana* including: ARSEF 6444 formulated as Mycotrol (Emeral Bioagriculture) (Brown et al. 1997, Noma and Strickler 1999 and 2000, Steintraus 1996, Steintraus and Tugwell 1997) and the *B. bassiana* strain ARSEF 3097 formulated as Naturalist (Snodgrass and Elzen 1994). Most of these investigations concluded that moderately effective control of TPB in cotton could be achieved using these commercial isolates.

Selections of virulent genotypes could be considered an important function for efficacious microbial control of TPB. Therefore, in order to identify new genotypes of *B. bassiana*, two surveys were conducted in the Mississippi Delta in 2003 (Leland and Snodgrass 2005). Several native strains of *B. bassiana* including the Delta native strain NI8 were found. For more than 10 years USDA - ARS Scientists from Mississippi, Arkansas, and California have studied this strain under laboratory and field conditions. These scientists demonstrated that NI8 has enhanced pathogenicity against TPB compared with the current commercial strain GHA. Leland (2005) and (MP unpublished data) compared 19 and 9 strains of *B. bassiana*, respectively. Those isolates were collected from Mississippi, Arkansas, California, and compared with the commercial GHA strain. It was found that NI8, under laboratory conditions, was significantly more pathogenic than GHA (based on LC_{50} values) with several strains having LC_{50} values more than 10-fold lower than *B. bassiana* GHA. Portilla et al. (2013) also demonstrated that NI8 strain has high pathogenicity against TPB under field conditions. That study demonstrated that reductions of 50 per cent of adult TPB populations 10 days post-spray using concentrations approximately 73-fold lower than that of the commercial strain GHA. McGuire et al (2006) found high virulence in the field to WTPB when comparing NI8 against strains from California and the GHA. Portilla et al. (2014b) found no significant differences in infection between direct spray and contact, obtaining greater than 50 per cent mortality 10 days after application with NI8 and less than 30 per cent with GHA. All published results of the pathogenicity of NI8 against TPB (Leland and Snodgrass 2005, Leland 2005, Leland et al. 2005, Leland and Behle 2004 and 2005, McGuire et al. 2005, McGuire et al. 2006, Lund et al. 2006b, Ugine 2011, and 2012, Portilla et al. 2013, Portilla et al. in press) suggest that despite its high level of infection, this pathogenic fungus may not represent the most suitable role for TPB control alone, not only because no significant reduction of adult populations occurred until 10-14 days after application, but because a variety of environmental factors could affect its efficacy such as solar radiation. However, this strain should be considered as an IPM component for TPB suppression, which will contribute to reduced chemical pesticide use. A detailed description of results of TPB control research using *B. bassiana* strain NI8 is presented in another paper in this special edition.

Beauveria bassiana has been employed with success against a variety of different insects in a variety of different agro-ecosystems. In the case of TPB populations in cotton, multiple efforts might need to be taken. It is well documented that weeds near cotton fields have been considered an important source of TPB moving into cotton (Fletcher 1930, Schuster et al. 1969, Fleischer and Gaylor 1987, Robbins et al. 2000, Snodgrass and Scott 2000, Stewart and Layton 2000, Carriere et al. 2006), and have also confirmed that cotton is not a suitable or preferred host for TPB. Most of the studies have shown that TPB population densities were significantly lower in cotton than in the other field types, such as forage and weeds, in which TPB population was equally abundant. Therefore, application of *B. bassiana* on suitability of vegetation patches of weedy TPB hosts should be considered for TPB management in the Mississippi Delta. Studies using herbicides and plant growth regulators have been conducted to evaluate TPB suppression in those agro-ecosystems (Snodgrass et al. 2006, Lund et al. 2006a and 2006b, Abel et al. 2007) but, further studies need to be conducted to evaluate their compatibility with *B. bassiana*.

Inhibitory effects of agrochemicals on germination and growth of entomopathogenic fungi often vary among taxa and strain (Vanninen and Hokkanen, 1988). Therefore, it may be possible to select genotypes which are naturally less susceptible (Inglis et al. 1996 and 2001). The Delta native strain NI8 may have such characteristics that enhance its efficacy against TPB when applied in combination with Novaluron. Snodgrass (Personal communication) observed higher mortality and infection of TPB on field plots of cotton spray with *B. bassiana* NI8 plus Novaluron than in those plots sprayed with *B. bassiana* or Novaluron alone. Lund et al. 2006a also found higher early mortality with the combination of *B. bassiana* NI8 and Novaluron. Using a combination of *B. bassiana* and herbicides should be considered based on results obtained by Abel et al. (2007) who developed a method which involved one application. This single application was to marginal areas near roads, fields, and ditches of an herbicide that selectively kills key spring broadleaf hosts of TPB. The average reduction of TBP population was 45.5 and 47 per cent for adults and nymphs, respectively.

Conclusion

Mycopesticides are often based on an indigenous rather than exotic fungal pathogen. The native strain NI8 of *B. bassiana* is already in the Mississippi Delta. Frequency of natural infection of TPB with NI8 is higher in areas undisturbed by agriculture practices. Undisturbed habitat is also often preferred by parasitoids and predators of TPB. However, extensive laboratory host-range bioassays have demonstrated that NI8 does not affect the most common beneficial insects present in both cotton and weedy hosts of TPB in the Mississippi Delta. Predators such as big-eyed bugs, lady beetles, spiders, and minute pirate bugs will be killed by *B. bassiana* with LC_{50} values greater than 3-fold the LC_{50} needed to kill TPB (MP unpublished data). In general, *B. bassiana* strain NI8 and some egg and nymphal parasitoids such as *A. iole* and *P. digoneutis* have demonstrated their effectiveness against TPB. However, it is clear that they will not play a prominent role in TPM management unless those biological agents are an integral component of a TPB suppression program.

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