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Impacts of transgenic *cry1Ab* rice on non-target planthoppers and their main predator *Cyrtorhinus lividipennis* (Hemiptera: Miridae)—A case study of the compatibility of Bt rice with biological control

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Abstract

Transgenic rice containing insecticidal protein(s) from Bt (*Bacillus thuringiensis*) effectively control lepidopteran pests under laboratory and field conditions. However, Bt rice has not been widely commercialized. A major concern regarding the deployment of Bt rice is its potential impact on non-target arthropods, including herbivorous insect pests and biological control agents (predators and parasitoids) in the rice ecosystem. A 2-year field study was conducted at 3 sites in Zhejiang Province, China to assess the impacts of a homozygous transgenic *japonica* rice line KMD1 (Bt rice) containing a synthetic *cry1Ab* gene from *Bacillus thuringiensis* Berliner. The impacts on three planthoppers (Homoptera: Delphacidae), *Sogatella furcifera* (Horváth), *Nilaparvata lugens* (Stål) and *Laodelphax striatellus* (Fallén), and the natural enemy, *Cyrtorhinus lividipennis* (Reuter) (Hemiptera: Miridae), were evaluated using two sampling methods: vacuum-suction and Malaise trap. Population densities of planthoppers and *C. lividipennis* were not significantly affected by rice type (Bt/non-Bt) over the season at any of the 3 sites in each year, regardless of sampling methods. Both in Bt rice and non-Bt rice plots, *S. furcifera* was the predominant species of planthoppers as determined by either of the two sampling methods, and comprised >50% of the planthoppers at each site. No consistent effects of Bt rice and Bt rice × sampling date interaction on population dynamics of the predominant planthopper species, *S. furcifera,* and the predator, *C. lividipennis*, were observed throughout the sampling period. Overall, this 2-year field study indicates that, in comparison with non-Bt rice, Bt rice did not lead to higher planthopper populations and did not negatively affect the predator *C. lividipennis*. These results suggest that use of Bt rice may provide control of the key lepidopteran pests while promoting the key biological control agent of planthopppers, *C. lividipennis.*

Keywords: Transgenic rice; *Bacillus thuringiensis*; Planthopper; Predator; *Cyrtorhinus lividipennis*; Biological control

1. Introduction

Rice is the most widely consumed cereal grain worldwide and was grown on over 149 million ha worldwide in 2004 (U.S. Department of Agriculture National Agricultural Statistics Service, 2005). China is the largest producer of rice accounting for 32–35% of total world production

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(Maclean et al., 2002). The main lepidopterous pests of rice in China are the striped stem borer *Chilo suppressalis* (Walker) (Lepidoptera: Pyralidae), yellow stem borer *Scirpophaga incertulas* (Walker) (Lepidoptera: Pyralidae), pink stem borer *Sesamia inferens* (Walker) (Lepidoptera: Noctuidae) and the leaffolder *Cnaphalocrocis medinalis* (Gueneé) (Lepidoptera: Pyralidae), which together annually cause a 3–10% yield loss despite the intense use of insecticides (Pathak and Khan, 1994; Sheng et al., 2003). The broad-spectrum insecticides commonly used in rice production have disrupted many biological control agents in the rice ecosystem and reduced their effectiveness for control of the Lepidoptera and other pest herbivores (Matteson, 2000). Alternative strategies for control of the lepidopteran pests in rice that are compatible with biological control are sorely needed. Transgenic plants producing insecticidal proteins of *Bacillus thuringiensis* (Bt) provide successful control of lepidopteran pests on cotton and maize and have been shown to be compatible with natural enemies (Naranjo et al., 2005; Romeis et al., 2006). In 2006, Bt plants were grown on 32.1 million ha worldwide (James, 2006).

Since 1993, numerous genotypes of Bt rice have been developed that confer high resistance against rice stem borers and leaffolders (Reviewed by High et al., 2004; Chen et al., 2006a). Bt rice field trials have been conducted in China since 1998, and indicate that Bt rice can effectively control stem borers and leaffolders (Chen et al., 2006a). However, Bt rice has not been approved for commercial release in China. One major concern about the deployment of Bt rice is its potential impact on non-target arthropods, including herbivorous insect pests and natural enemies. Bernal et al. (2002) found that Bt insecticidal protein could be taken up by *Nilaparvata lugens* (Stål) (Homoptera: Delphacidae) that fed on transgenic Bt rice and subsequently occur in its natural enemy, *Cyrtorhinus lividipennis* (Reuter) (Hemiptera: Miridae). Chen et al. (2005) reported similar results with *N. lugens and* its predator, *Pirata subpiraticus* (Bösenberg et Strand) (Araneae: Lycosidae) when the former fed on Bt rice. Thus, there is evidence that Bt proteins in transgenic rice may occur in the natural enemy food chain, although it is not clear what ecological consequences, if any, may arise from this phenomenon. Previous studies have indicated that Bt cotton and maize are not effective against non-lepidopteran herbivorous pests such as sucking pests (Hilder and Boulter, 1999). Furthermore, others have found that sucking pests are not exposed to Bt proteins because the proteins do not appear to be transported in the phloem (Head et al., 2001; Raps et al., 2001). However, Ashouri et al. (2001) reported that *Macrosiphum euphorbiae* (Thomas) (Homoptera: Aphididae) had reduced growth and fecundity when reared on Cry3A potatoes and *N. lugens* generated less honeydew when fed on Bt rice than when fed on conventional non-Bt rice (Chen et al., 2003a,b). Under field conditions, significantly higher abundance of leafhoppers, primarily *Empoasca fabae* (Harris) (Homoptera: Cicadellidae) and *Aphis gossypii* (Glover) (Homoptera: Aphididae) was reported in Bt potato (Riddick et al., 1998) and Bt cotton fields (Cui and Xia, 2000), respectively.

In Asia, planthoppers are important rice insect pests and some species such as *Sogatella furcifera* (Horvath) (Homoptera: Delphacidae) and *N. lugens* often cause more yield loss than either stem borers or leaffolders (Dale, 1994). *C. lividipennis* is an important predator of the egg and nymphal stages of planthoppers and can keep planthopper populations at a low level (Chiu, 1979; Liquido and Nishida, 1983). Planthoppers are likely exposed to Bt insecticidal proteins when they feed on Bt rice (Bernal et al., 2002; Chen et al., 2005) but it is less clear, under an actual rice ecosystem, if this will have any impact on the population densities and dynamics of non-target planthoppers and their important predators such as *C. lividipennis.* Information on its potential effect is needed as part of an environmental risk assessment prior to the commercial release of Bt rice.

In order to evaluate the impacts of Bt rice on non-target planthoppers and the predator *C. lividipennis*, a 2-year field study was conducted at three different sites in Zhejiang Province in China.

2. Materials and methods

2.1. Plant material

Bt rice, KMD1 at the 9th and 10th generation after transformation, was selected for field evaluation in 2002 and 2003, respectively, together with its non-Bt parental *japonica* rice cultivar Xiushui11. The Bt rice contained a synthetic *cry1Ab* gene under the control of the maize *ubiquitin* promoter and linked in tandem with *gus* (encoding the β-glucuronidase), *hpt* (encoding the hygromycin phosphotransferase) and *npt* (encoding the neomycin phosphotransferase) genes (Cheng et al., 1998; Xiang et al., 1999). The Bt rice selected through four generations was homozygous for the transgenes (*cry1Ab*, *gus* and *npt*) (Shu et al., 1998), and effectively controls rice stem borers (Ye et al., 2001) and leaffolders (Ye et al., 2003) under field conditions.

2.2. Field planting

Both in 2002 and 2003, experiments were conducted at three different sites in Zhejiang Province, China where planthoppers occurred naturally during the rice growing seasons. The first site was in the suburb of Anji County (119.35°E, 30.88°N); the second site was at the Experimental Farm of Zhejiang University in Hangzhou City (120.12°E, 30.13°N); and the third site was at the Huajiachi Farm of Zhejiang University. Each year, Bt and non-Bt rice were transplanted 1 month after sowing and in both years the sowing and planting dates were the same for each location. The first planting was sown on April 21, and transplanted on May 21 at the Huajiachi Farm of Zhejiang University. The second planting was sown on May 27, and transplanted on June 27 at the Experimental Farm. The third planting was sown on June 20, and transplanted on July 20 at the local experimental field in the suburb of Anji County. Each field was divided into six experimental plots in a 2 (treatments, Bt vs non-Bt) × 3 (replications) completely randomized design. Each experimental plot was 20 m × 35 m in Anji County and 20 m × 25 m in the other locations. Each plot was bordered on all sides by an unplanted 50 cm-wide earthen walkway. Seedlings were hand transplanted at one seedling per plant or hill spaced 16.5 cm × 16.5 cm apart, and the entire experimental field was surrounded by five border rows of the untransformed control plants. Normal cultural practices for growing rice, such as fertilization and irrigation, were followed during the course of the experiment except that no insecticides were applied after sowing and transplanting.

2.3. Sampling by vacuum-suction machine

Population dynamics of planthoppers and the predator *C. lividipennis* at all 3 sites were evaluated using a vacuum-suction machine. The machine was based on a description by Carino et al. (1979), supplemented with a square sampling frame (50 cm × 50 cm × 90 cm high with a planar area of 2500 cm^2) made of Mylar sheets to enclose nine rice hills. Samples were taken in all plots on a 15 ± 1 d schedule starting ca. 1 month after transplant until the rice was fully grown (ca. 65 d for each year). On each sampling date, a square sampling frame was placed at random along the diagonal line of each tested plot at each site, with five sub-samples per plot. The sample location in each plot was marked with a bamboo stake that was left in place for the next sampling dates, at which time the marked location was not sampled again. Arthropods inside the frame enclosure were removed by the vacuum-suction machine at each sampling location, and then transferred into a coded glass vial containing 75% ethanol. All samples were returned to the laboratory for sorting and counting planthopper and *C. lividipennis* individuals, including nymphs and adults.

At the Huajiachi Farm there were five sampling dates in 2002 and six sampling dates in 2003. Each year, there were seven sampling dates at the Experimental Farm, and five at Anji.

2.4. Sampling by Malaise trap

A Malaise trap (Walker, 1978), with a peak that contained a vial with 500 ml of 75% ethanol, was used to monitor the population dynamics of planthopper and *C. lividipennis* adults at the Experimental Farm of Zhejiang University in Hangzhou. The Malaise trap was 2.0 m long by 1.5 m wide by 1.8 m high. One Malaise trap, enclosing about 96 rice hills (a hill is a group of tillers grown in one hole), was placed at the center of each of the six plots. The ethanol vials with arthropods were collected at 08:00 and replaced daily. Planthopper and *C. lividipennis* adults in the samples were sorted and counted with the aid of a microscope in the laboratory. The sampling was initiated about 5 weeks after transplanting and continued until the rice plants were fully grown (ca. 65 d for each year).

2.5. Statistical analyses

In order to evaluate the overall impact of Bt treatment on population densities of planthoppers and predator, density of each species captured by vacuum-suction and Malaise trap over the season (seasonal means) was analyzed using GLM PROC and Fisher's protected LSD mean separation test (SPSS version 11.5 for windows, 2002). The rice type (Bt treatment) variable was entered as fixed factor, and the site and year variables were entered as random factors. All count data were square root $(X + 1)$ or $\log_{10}(X + 1)$ transformed, as necessary, before univariate analysis, but untransformed means are presented. Since Bt treatment may have a possible chronic effect on planthoppers and the predator population, rice type × sampling date interaction was considered on population dynamics (means by sampling date) of the predominant species of planthoppers (nymphs and adults) and *C. lividipennis* (nymphs and adults) collected by Malaise trap and vacuum-suction (Daly and Buntin, 2005), which were analyzed using two-way ANOVA (rice type vs sampling date) for each species within each year/site. The number of planthoppers and *C. lividipennis* captured by Malaise trap was summed for per week per trap and analyzed as described above because of the very low capture of *C. lividipennis* at most sampling dates. All statistical calculations were performed using the SPSS package. For all tests, $\alpha = 0.05$.

3. Results

3.1. Population density

Three species of planthoppers (*S. furcifera*, *N. lugens*, and *Laodelphax striatellus* (Fallén) (Homoptera: Delphacidae)) were collected by the vacuum-suction from Bt and non-Bt plots at the 3 sites in 2002 and 2003. However, *L. striatellus* was not captured in any plots using a Malaise trap. The density over the season of each species of planthoppers and the predator *C. lividipennis*, as determined by sampling with the vacuum-suction, is shown in Table 1. Density of *S. furcifera* was not significantly affected by rice type (Bt/non-Bt, $F = 0.003$, df = 1,48; $P = 0.965$), regardless of test site and year. Similarly, densities of *L. striatellus* and *N. lugens* were not significantly affected by rice type over different site and year ($F = 0.753$, df = 1,48; $P = 0.572$ and $F = 0.426$, df = 1,48; $P = 0.577$). Bt rice did not significantly affect the density of *C. lividipennis* in comparison with non-Bt rice ($F = 7.091$, df = 1,48; $P = 0.229$). Densities of planthopper species captured by Malaise trap are showed in Table 2. Densities of *S. furcifera and N. lugens* were not significantly affected by rice type ($F = 65.809$, df = 1,8; $P = 0.078$ and $F = 1.842$, df = 1,8;

Table 1
Densities (mean ± SE) of planthopper species and *Cyrtorhinus lividipennis* collected by vacuum-suction in Bt and non-Bt rice in 2002 and 2003 at three sites in China

Year	Species	Huajiachi Farm		Experimental Farm		Anji	
		Bt	Non-Bt	Bt	Non-Bt	Bt	Non-Bt
2002	Delphacidae						
	S. furcifera	1.40 ± 0.50	2.24 ± 0.60	9.17 ± 1.48	10.66 ± 1.96	2.86 ± 0.45	2.90 ± 0.34
	N. lugens	0.48 ± 0.19	0.20 ± 0.08	0.63 ± 0.23[a]	5.03 ± 1.57	0.98 ± 0.18	0.84 ± 0.19
	L. striatellus	0.96 ± 0.30	1.76 ± 0.48	0.57 ± 0.19	1.46 ± 0.29	0.76 ± 0.18	0.56 ± 0.14
	Miridae						
	C. lividipennis	0.3 ± 0.09	0.4 ± 0.16	2.51 ± 0.63	3.11 ± 0.74	0.52 ± 0.14	0.4 ± 0.14
2003	Delphacidae						
	S. furcifera	0.97 ± 0.23	0.90 ± 0.18	37.17 ± 7.12	29.60 ± 5.68	3.46 ± 0.40	2.84 ± 0.33
	N. lugens	0	0.07 ± 0.07	1.00 ± 0.37	1.63 ± 0.45	1.18 ± 0.17	0.98 ± 0.18
	L. striatellus	0.50 ± 0.21	0.10 ± 0.07	0.97 ± 0.23	0.77 ± 0.18	0.94 ± 0.17	0.78 ± 0.13
	Miridae						
	C. lividipennis	0.13 ± 0.06	0.17 ± 0.07	0.83 ± 0.17	1 ± 0.27	0.2 ± 0.13	0.6 ± 0.15

$n = 3$ at each site in 2002 and 2003.

[a] Significantly different from the non-Bt control ($P < 0.05$); otherwise, there were no significant differences between Bt and non-Bt plots (Fisher's protected LSD mean separation test).

Table 2
Densities (mean ± SE) of planthopper species and *Cyrtorhinus lividipennis* collected by Malaise trap in Bt and non-Bt rice in 2002 and 2003 at the Experiment Farm of Zhejiang University in China

Year	Species	Density (No./trap/day)	
		Bt	Non-Bt
2002	*S. furcifera*	2.91 ± 0.52[a]	4.58 ± 0.87
	N. lugens	0.07 ± 0.03[a]	0.12 ± 0.04
	C. lividipennis	0.41 ± 0.05	0.37 ± 0.04
2003	*S. furcifera*	3.75 ± 0.69[a]	5.19 ± 0.76
	N. lugens	0.17 ± 0.07[a]	0.58 ± 0.20
	C. lividipennis	0.34 ± 0.04	0.40 ± 0.05

$n = 3$ in 2002 and 2003.

[a] Significantly different from the non-Bt control ($P < 0.05$); otherwise, there were no significant differences between Bt and non-Bt plots (Fisher's protected LSD mean separation test).

$P = 0.404$). Moreover, density of the predator *C. lividipennis* was very similar between Bt rice and non-Bt rice plots ($F = 11.988$, df = 1,8; $P = 0.179$) (Table 2). Both in Bt and non-Bt plots, *S. furcifera* was the predominant species of planthoppers as determined by either of the two sampling methods, and comprised >50% of the planthoppers at any of the 3 sites. Species abundance of planthoppers with vacuum-suction at the Huajiachi Farm was *S. furcifera* > *L. striatellus* > *N. lugens,* while *S. furcifera* > *N. lugens* > *L. striatellus* at the Experimental Farm and Anji.

3.2. Population dynamics

The Malaise trap samples indicate that, in 2002, population dynamic of the predominant planthopper species, *S. furcifera,* was significantly affected by Bt rice ($F = 25.674$, df = 1,40; $P < 0.001$) and the interaction of Bt rice with sampling date ($F = 4.580$, df = 9,40; $P < 0.001$) (Fig. 1). However, in 2003, population dynamic of *S. furcifera* was not significantly affected by rice type ($F = 4.580$, df = 1,36; $P = 0.074$) and Bt × date interaction ($F = 4.580$, df = 8,36; $P = 0.705$). In addition, population dynamic of the predator, *C. lividipennis,* was not significantly affected by rice type and Bt × date interactions both in 2002 ($F = 0.965$, df = 1,40; $P = 0.332$ and $F = 1.332$, df = 9,40; $P = 0.251$) and in 2003 ($F = 0.815$, df = 1,36; $P = 0.373$ and $F = 1.528$, df = 8,36; $P = 0.182$) (Fig. 1).

Vacuum-suction samples indicate that population dynamics of the nymph or adult stages of the predominant species of planthoppers *(S. furcifera)* and the predator *C. lividipennis* were very similar between Bt and non-Bt rice at the Huajiachi Farm (Fig. 2), the Experimental Farm (Fig. 3) and Anji (Fig. 4) in each year. Bt treatment and Bt × date interaction did not significantly affect *S. furcifera* and *C. lividipennis* population dynamics (Table 3), except that *C. lividipennis* adults were significantly affected by Bt rice ($F = 8.148$, df = 1,56; $P = 0.006$) and Bt × date interaction ($F = 2.318$, df = 5,56; $P = 0.045$) at the Experimental Farm in 2002; *S. furcifera* nymphs were significantly affected by Bt × date interaction ($F = 3.981$, df = 5,56; $P = 0.002$) at the Experimental Farm in 2003 (Table 3). No consistent impact was found.

4. Discussion

One of the risks associated with the growing of insect-resistant crops is their potential to adversely effect non-target organisms including herbivorous insect pests and biological control agents. Thus, data are needed as part of environmental risk assessment prior to the cultivation of any transgenic crop. There are no clear international guidelines for such evaluation, but most field studies evaluating the impacts of Bt crops (cotton, maize and potatoes) on non-target pest herbivores and natural enemies have focused on abundance, species richness and diversity (Naranjo et al., 2005). The major goal of field trials has been to evaluate whether Bt crops would change the ecological balance under field conditions, and would be compatible with

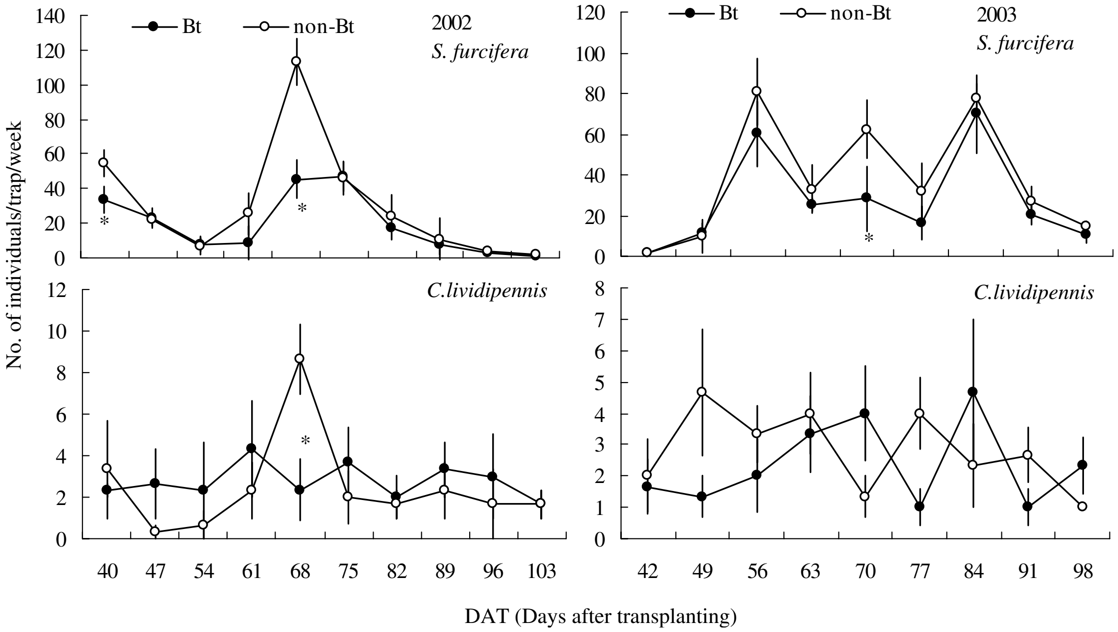

Fig. 1. Mean (±SE) number of *Sogatella furcifera* and *Cyrtorhinus lividipennis* adults captured by Malaise trap in Bt and non-Bt rice in 2002 (left) and 2003 (right) at the Experiment Farm of Zhejiang University, China. $n = 3$ in 2002 and 2003. Bt point marked * is significantly different from non-Bt ($P < 0.05$); otherwise, there are no significant differences between Bt and non-Bt (Fisher's protected LSD mean separation test).

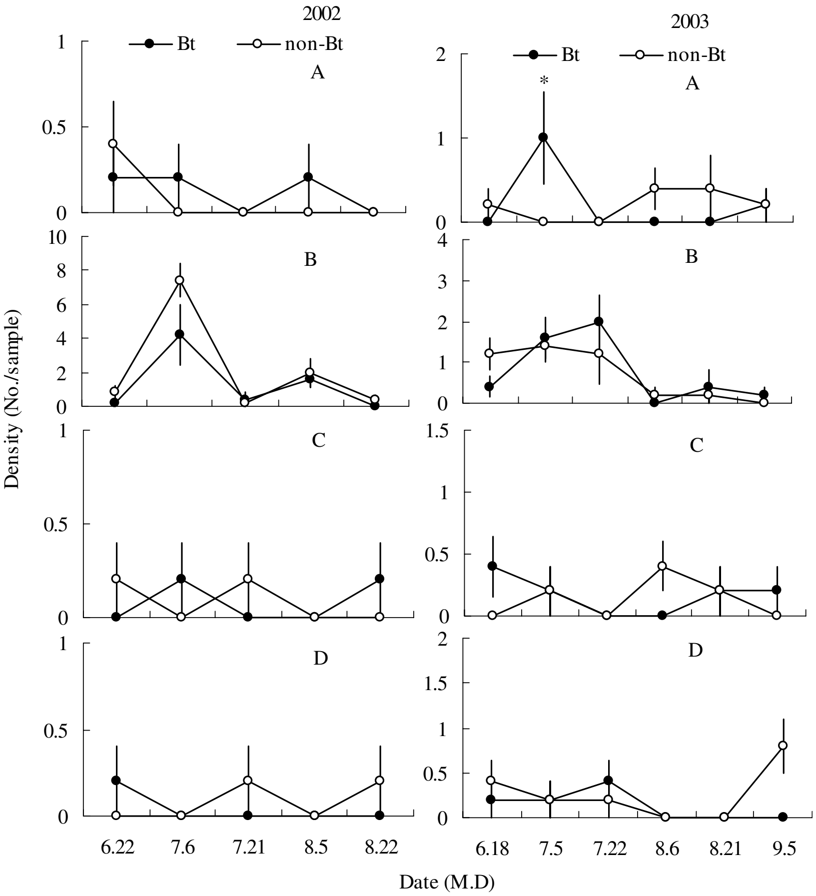

Fig. 2. Mean (±SE) number of *Sogatella furcifera* and *Cyrtorhinus lividipennis* captured by vacuum-suction in Bt and non-Bt rice in 2002 (left) and 2003 (right) at the Huajiachi Farm of Zhejiang University, China. (A) *S. furcifera* nymphs, (B) *S. furcifera* adults, (C) *C. lividipennis* nymphs, (D) *C. lividipennis* adults. $n = 3$ at each site in 2002 and 2003. Bt point marked * is significantly different from non-Bt ($P < 0.05$); otherwise, there are no significant differences between Bt and non-Bt (Fisher's protected LSD mean separation test).

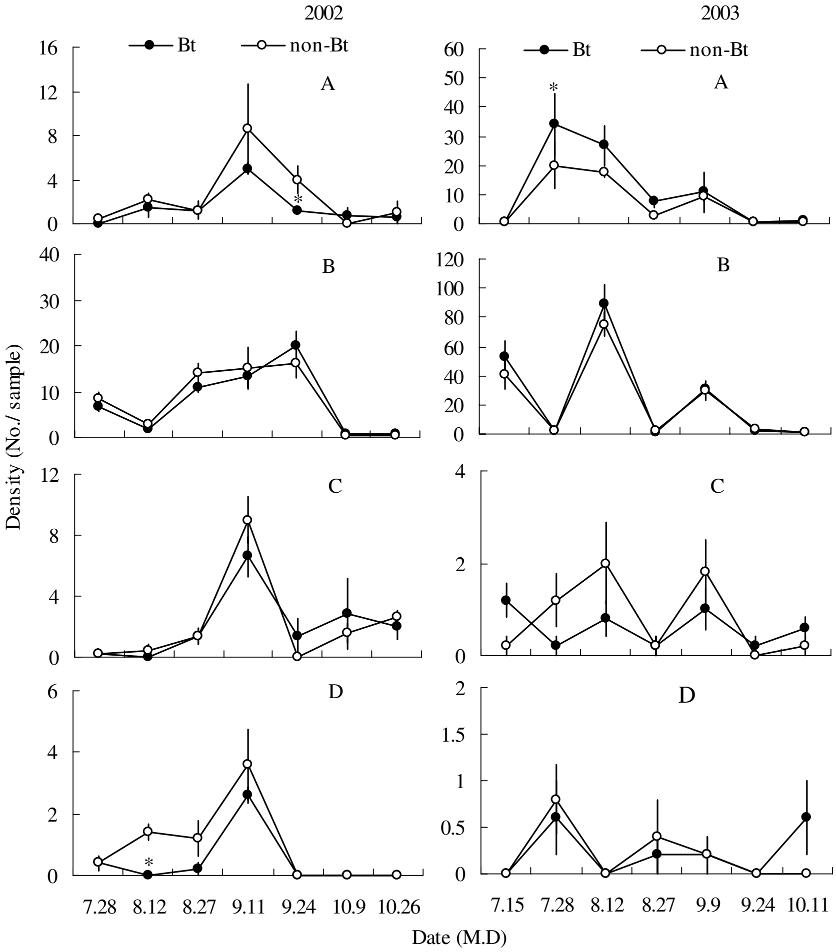

Fig. 3. Mean (±SE) number of *Sogatella furcifera* and *Cyrtorhinus lividipennis* captured by vacuum-suction in Bt and non-Bt rice in 2002 (left) and 2003 (right) at the Experimental Farm of Zhejiang University, China. (A) *S. furcifera* nymphs, (B) *S. furcifera* adults, (C) *C. lividipennis* nymphs, (D) *C. lividipennis* adults. $n = 3$ at each site in 2002 and 2003. Bt point marked * is significantly different from non-Bt ($P < 0.05$); otherwise, there are no significant differences between Bt and non-Bt (Fisher's protected LSD mean separation test).

biological control. With the introduction of a new pest management practice, including a new insecticide or insect-resistant cultivar, it is important to determine any effect on other members of the system so that ecological problems can be avoided. For instance, planthoppers were only a minor insect pest group on rice in China before the 1970s. However, the adoption of broad-spectrum chemical insecticides and hybrid rice resulted in them becoming a major pest since 1980s (Sogawa et al., 2003). Whether the use of Bt rice will lead to similar problems is a major concern that needs to be addressed prior to commercialization of Bt rice.

Our 2-year field studies indicated that there were no significant differences in the population densities of non-target planthoppers and predator *C. lividipennis* in the Bt and non-Bt rice plots measured either by vacuum-suction or Malaise trap (Tables 1 and 2). Moreover, it is noteworthy that the overall densities of planthoppers were even lower in Bt rice than those in non-Bt rice at some cases, suggesting that planthoppers would be less problematic and cause less damage in Bt rice than in non-Bt rice. Population dynamics of *S. furcifera* adults with Malaise trap (Fig. 1) and *C. lividipennis* adults with vacuum-suction in 2002 (Fig. 3) at one test site were markedly affected by Bt rice. It is unclear whether the effect was due to Bt rice or statistical analysis or relatively small plot size. However, no consistent impact of Bt rice and Bt × date interaction were observed on the population dynamics of *S. furcifera* and *C. lividipennis* (nymphs and adults) throughout the sampling period. The above results were similar to a previous study conducted in 2000 using vacuum-suction, providing additional evidence that there were no significant differences in the densities of *S. furcifera* and *N. cincticeps* between the plots of two Bt rice lines, i.e. TT9-3 and TT9-4 (two lines both contained a fused Bt gene of *cry1Ab* and *cry1Ac*) and their control (IR72) (Liu et al., 2002). In a 6-year field study, Naranjo (2005) reported that no chronic, long-term effects of Bt cotton were observed over multiple generations of non-target taxa compared with non-Bt cotton. In contrast, strong negative impacts were found when insecticides were applied for controlling Lepidoptera and other pests in both non-Bt and Bt cotton fields. Similarly, Liu et al. (2004) did not find significant differences in non-target

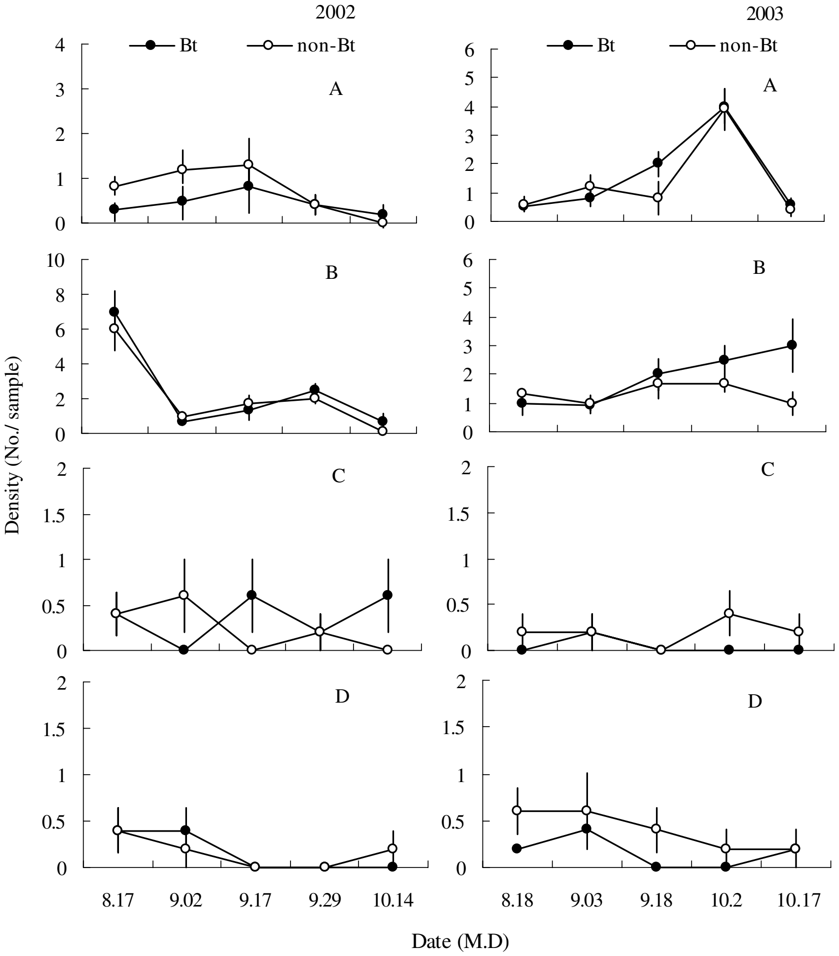

Fig. 4. Mean (±SE) number of *Sogatella furcifera* and *Cyrtorhinus lividipennis* captured by vacuum-suction in Bt and non-Bt rice in 2002 (left) and 2003 (right) in Anji, China (A) *S. furcifera* nymphs, (B) *S. furcifera* adults, (C) *C. lividipennis* nymphs, (D) *C. lividipennis* adults. $n = 3$ at each site in 2002 and 2003. No significant differences were found between Bt and non-Bt (Fisher's protected LSD mean separation test) ($P < 0.05$).

Table 3

Statistical results of Bt main effect and Bt × date interaction on *Sogatella furcifera* and *Cyrtorhinus lividipennis* population dynamics measured by vacuum-suction in Bt and non-Bt rice in 2002 and 2003 at three sites in China

Insect	Site	Bt main effect[a]				Bt × date interaction[b]			
		2002		2003		2002		2003	
		F	*P*	*F*	*P*	*F*	*P*	*F*	*P*
S. furcifera nymphs	Huajiachi Farm	2.000	0.165	0.116	0.735	0.333	0.854	2.143	0.076
	Experimental Farm	2.011	0.078	3.486	0.067	1.788	0.097	3.981	0.002[c]
	Anji	3.408	0.072	0.106	0.746	1.140	0.152	0.668	0.618
S. furcifera adults	Huajiachi Farm	2.280	0.139	0.103	0.749	0.502	0.735	1.182	0.332
	Experimental Farm	0.163	0.688	0.262	0.612	2.133	0.064	1.116	0.365
	Anji	0.845	0.363	1.600	0.214	0.798	0.534	2.134	0.094
C. lividipennis nymphs	Huajiachi Farm	0.003	0.969	0.160	0.613	1.250	0.306	0.981	0.439
	Experimental Farm	0.214	0.214	0.013	0.910	0.787	0.584	1.701	0.138
	Anji	0.520	0.475	0.002	0.981	1.821	0.144	0.385	0.818
C. lividipennis adults	Huajiachi Farm	0.333	0.567	0.560	0.458	1.167	0.340	0.711	0.618
	Experimental Farm	8.148	0.006[c]	0.004	0.949	2.318	0.045[c]	0.466	0.831
	Anji	0.004	0.935	0.158	0.693	0.385	0.818	0.557	0.695

[a] df = 1,40 in 2002 and df = 1,48 in 2003 at the Huajiachi Farm; df = 1,56 at the Experimental Farm and df = 1,40 at Anji for each year.

[b] df = 4,40 in 2002 and df = 5,48 in 2003 at the Huajiachi Farm; df = 6,56 at the Experimental Farm and df = 4,40 at Anji for each year.

[c] Significance at $P < 0.05$.

organisms between Bt and non-Bt rice; however, the guild dominance of herbivores and parasitoids, and composition of predators and detritivores in non-Bt rice paddies were significantly affected by chemical insecticides compared with non-insecticide treatments in both Bt and non-Bt rice fields. In a commentary on a collection of field studies in cotton and corn, Naranjo et al. (2005) concluded that the collective field studies indicated that effects of Bt crops on the non-target community were minor, especially in comparison with the alternative use of broad-spectrum insecticides. Most insecticides currently used for the control of rice stem borers and leaffolder in China are broad-spectrum chemicals that are known to be harmful to natural enemies in rice fields (Tanaka et al., 2000). Insecticide-induced resurgence has been a serious problem in the management of rice planthoppers in recent years (Wang et al., 1994; Wu et al., 2001), especially after the outbreak of planthoppers in several provinces in China in 2005 (Cheng and Zhu, 2006; Gao et al., 2006). One key reason of the outbreak of planthoppers was that more broad-spectrum chemical insecticides were applied for lepidopterans and planthoppers control, which significantly reduced the number of natural enemies in rice fields (Cheng and Zhu, 2006; Gao et al., 2006). Large-scale testing of different Bt rice lines were approved in 2001 in China in experiment station fields and farmers' fields at >13 sites. These large-scale trails verified an 80% reduction in pesticide usage with yield increases of approximately 6–9% and an overall increase in net income per hectare of US $80–100 (Huang et al., 2005). An 80% reduction in the use of broad-spectrum insecticides will make a very important contribution to protect natural enemies and enhance biological control in the rice ecosystem, especially for the control of planthoppers, because insecticides are often toxic to the natural enemies of planthoppers, including *C. lividipennis* and *Microvelia airolineata* (Hemiptera: Veliidae) (Johnson et al., 1998). For instance, Ooi (1986) reported that rice did not suffer from planthopper-caused hopper-burn in plots without insecticide sprays because of the presence of predators, especially *C. lividipennis*; however, serious damage occurred in plots with regular sprays of insecticides.

Bt crops that target serious lepidopteran pests and significantly reduce chemical insecticide application have the potential to increase opportunities for biological control and lead to more fully integrated pest management programs (Cannon, 2000; Edge et al., 2001; Shelton et al., 2002; Romeis et al., 2006). Based on our results and previous studies (Liu et al., 2002, 2003; Chen et al., 2006b), it may be deduced that Bt rice has good compatibility with biological control in the rice ecosystem.

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