Pakistan J. Zool., vol. 42(5), pp. 559-565, 2010.

Toxicity of Thiamethoxam and Imidacloprid as Seed Treatments to Parasitoids Associated to Control *Bemisia tabaci*

Muhammad Naveed*, Abdus Salam, Mushtaq Ahmad Saleem, Muhammad Rafiq and Amir Hamza
Central Cotton Research Institute, Multan (MN, MR), Institute of Pure and Applied Biology, Bahauddin Zakariya University, Multan (AS, MAS), and Pakistan Agricultural Research Council Multan (AH)

Abstract.- Imidacloprid and thiamethoxam are being used for cotton seed treatment in cotton, *Gossypium hirsutum* L., to control various early season piercing and sucking pests. To assess the activity of these neonicotinoids against whitefly, *Bemisia tabaci* and their aphelinid parasitoids, cotton seed were treated with imidacloprid and thiamethoxam and sown in the field. Untreated seed were also sown as control treatment. The studies were continued for three years. During the study period, the population of *B. tabaci* remained below economic threshold level (6 $leaf^{-1}$) in all the treatments upto 50 days after sowing. It was significantly lower in the imidacloprid and thiamethoxam seed treated plots compared with untreated check plots during the same period. Parasitism in the treated plots was comparatively lower than untreated plots. During 2003, the seasonal mean percent parasitism in plot treated with imidacloprid was 12% less than untreated plots. During 2004 and 2005, the level of parasitism in imidacloprid plots was 23.8% and 21.9% less and in thiamethoxam it was 15.9% and 18.4% less compared with untreated check. Total parasitism in pooled data from these studies revealed that percent parasitism reduction in imidacloprid (19.2 %) and thiamethoxam (13.2%) was less compared with untreated. Comparatively, thiamethoxam proved less toxic to parasitoids compared with imidacloprid.

Keywords: *Bemisia tabaci*, seed treatment; imidacloprid, thiamethoxam, parasitism.

INTRODUCTION

B*emisia tabaci* (Genn.) *Amrasca devastans* (Dist) and *Thrips tabaci* (Lind) cause considerable damage (> 10%) to the cotton crop during its early stages of development resulting in pre-mature shedding of leaves and fruiting parts. In the early stage of growing the crop, farmers use foliar insecticides to avoid damage from these pests. These early foliar applications of insecticide often kill the natural enemies which then results in a resurgence of the pests, especially whitefly (Naveed, 2006). With the introduction of the systemic insecticides imidacloprid and thiamethoxam, for seed treatment, farmers have been able to use them to protect their crop from the early season, sap-sucking insect pests. The effects of imidacloprid and thiamethoxam on sucking pests (Kagabu, 1999; Yamada *et al.,* 1999; Maienfisch *et al.,* 2001) and their effects on predators are well documented (Woolweber and Tietjen, 1999).

However, very little information is available on the effect of these seed treatment insecticides on the parasitoids of *B. tabaci* under field conditions. Traditionally, parasitoids have been successful in suppressing whitefly and more than 70% parasitism has been recorded during early stage of the cotton crop (Naveed *et al.,* 2007) and need to be protected. Thus, in order to develop and conduct a successful IPM program, susceptibility of parasitoids to various insecticides especially the seed treatment should be known and taken into account.

Imidacloprid was the first neonicotinoid seed treatment insecticide used commercially to protect seeds and seedlings against injury by early season insects (Wilde *et al.,* 1999; Graham, 1998; Burd *et al.,* 1996; Almand, 1995; Mckirdy and Jones, 1996). It is also effective at controlling many insects, including aphids, thrips, jassid, mites, wireworms, and true bug when used as a seed treatment, and as soil and foliar applications (Bradley *et al.,* 1998; Graham *et al.,* 1995; Harvey *et al.,* 1996), and is commonly used on several crops, including cotton, wheat, barley, sorghum, canola, corn and sugar beets (Kerns and Palumbo, 1995; Woolweber and Tietjen, 1999; Hernandez *et al*., 1999).

Thiamethoxam is a second-generation neonicotinoid belonging to the thianicotinyl sub-class of the nicotinoid chemistry (Maienfisch *et al.,*

* Corresponding author: naveed_ento@yahoo.com
0030-9923/2010/0005-0559 $ 8.00/0

2001). It provides excellent control of a wide variety of commercially important insect pests on a variety of crops including barley, cotton, sorghum, wheat, canola, and corn through contact, stomach and systemic activity (Gobel *et al.*, 1999; Maienfisch *et al.*, 1999; Hofer and Brandl, 1999; Zang *et al.*, 1998; Lawson *et al.*, 1999).

This study was initiated to gain confidence on the safety of these compounds against the parasitoids in order to include these compounds for the management of early season sucking pest, especially the whitefly.

MATERIALS AND METHODS

Effect of seed treatment with imidacloprid and thiamethoxam on the population of whitefly and parasitoids were recorded and compared with untreated check during 2003-2005 cotton seasons. To treat seed, imidacloprid 70WS @ 8 gm/kg cotton seed was mixed in 200 ml of water. Insecticide solution and delinted cotton seed of commercial variety CIM-473 were vigorously shaken and rotated in plastic bag. Insecticide treated seed were then dried under the shade. Likewise, thiamethoxam 25WG @ 3 gm/kg seed was used for the second treatment and the above mentioned procedure was followed to treat seed with insecticide. The untreated seed were used as control treatments. Each year, the trial was sown in the 1st week of June. The experiment was laid out in a complete randomized block design, treatments were replicated 4 times having a plot size of 30 X 30.5 meter. Treated and untreated seed were sown by hand using a dibbing method on bed and furrow. The plots consisted of 50,000 plants per hectare spaced 0.25 cm within row and 0.8 m between rows. No foliar spray application was given during the study period.

Observations

Whitefly

Both nymph and adult population of whitefly were recorded by using leaf turn method (Ellsworth *et al*., 1995; Naranjo *et al*., 1996). Fifteen randomly selected leaves from 5th to 8th main stem down from terminal were taken from each plot and observations were continued from 30 days after sowing (DAS) to 70 DAS at 10 days interval.

Whitefly parasitoids

Twenty leaves infested with the highest number of 3rd instar nymphs of whitefly per plot were harvested and brought back to the laboratory on each observation date. This procedure started from 30 to 70 DAS at 10 day intervals. Afterwards, a leaf disc displaying the highest number of 3rd instar nymphs was cut with the help of a leaf cutter of size (20 cm^2). At least 20 leaf discs per plot per observation were kept in glass Petri dishes with their lids on in the laboratory at 28 $\pm$ 2 °C and 65 $\pm$ 3% RH (Naveed *et al.*, 2007). The numbers of whitefly and their parasitoid adults that emerged were recorded. Percentage parasitism was defined as: percent parasitism = ((number of emerged parasitoids) / (number of emerged parasitoids + number of whitefly)) X 100.

Data analysis

The population of whitefly recorded in the field and the percentage parasitism recorded in the laboratory were analyzed by analysis of variance (ANOVA) for each observation (Gomez and Arturo, 1984). Treatments means were compared by using Fishers' LSD test.

RESULTS

Effect on whitefly

During 2003, *B. tabaci* remained below economic threshold level (ETL, 6 leaf $^{-1}$) in all the treatments upto 50 DAS. Comparatively population of whitefly in both imidacloprid and thiamethoxam seed treated plots were significantly lower than untreated plots at 30 DAS (F= 15.57; df= 2, 6; P < 0.01), 40 DAS (F= 8.42; df= 2, 6; P < 0.01), and 50 DAS (F= 5.87; df= 2, 6; P < 0.01). It was significantly higher and above ETL in untreated plot compared with seed treated plots (F= 15.64; df= 2, 6; P < 0.01) at 60 DAS. Population of whitefly was above ETL in all the treatments and difference among all the treatments were non significant (F= 3.15; df= 2,6; P<0.01) at 70 DAS whereas, maximum number of whitefly was in thiamethoxam seed treated plots (20.1) followed by untreated plots (16.4) (Table I).

Table I.- Field population of *B. tabaci* per leaf during 2003 – 2005.

Treatments	Days after sowing (DAS)				
	30	40	50	60	70
2003					
Imidacloprid	1.7	2.0	2.5	3.6	15.8
Thiamethoxam	1.5	2.6	3.0	4.2	20.1
Untreated	3.4	4.1	5.6	6.1	16.4
LSD (5%)	**0.92**	**1.29**	**2.38**	**1.14**	**4.54**
2004					
Imidacloprid	1.1	2.4	2.6	5.6	7.0
Thiamethoxam	2.0	2.5	3.1	6.5	8.1
Untreated	3.7	4.5	5.3	7.8	8.5
LSD (5%)	**1.11**	**1.08**	**1.63**	**1.73**	**1.29**
2005					
Imidacloprid	1.5	2.4	2.8	4.8	11.5
Thiamethoxam	1.9	3.0	3.5	5.5	14.5
Untreated	2.8	4.5	5.8	6.9	13.4
LSD (5%)	**0.40**	**0.41**	**0.84**	**1.65**	**2.32**

During 2004, *B. tabaci* also remained below ETL in all the treatments upto 50 DAS. Comparatively population of whitefly in both imidacloprid and thiamethoxam seed treated plots were significantly lower than untreated plots at 30 DAS (F= 17.05; df= 2, 6; P < 0.01), 40 DAS (F= 14.43; df= 2, 6; P < 0.01), and at 50 DAS (F= 9.28; df= 2, 6; P<0.01). It was above ETL in thiamethoxam (6.5) and untreated check (7.8) at 60 DAS whereas, the population difference among all the treatments was non significant (F= 4.89; df= 2, 6; P < 0.01). At 70 DAS, the population of whitefly was above ETL in all the treatments and the difference among the treatments was non significant (F= 4.34; df= 2, 6; P < 0.01) (Table I).

During 2005, a similar trend in the population of *B. tabaci* was recorded and it remained below ETL in all the treatments upto 50 DAS. Comparatively population of whitefly in both imidacloprid and thiamethoxam seed treated plots were significantly lower than untreated plots at 30 DAS (F= 33.25; df= 2, 6; P < 0.01), 40 DAS (F= 84.24; df= 2, 6; P < 0.01), and at 50 DAS (F= 42.23; df= 2, 6; P < 0.01). It was recorded above ETL in untreated check plot but the difference among the seed treated and untreated plots were non significant (F= 5.03; df= 2, 6; P < 0.01) at 60 DAS. Whitefly population was above ETL in all the treatments and the difference among the treatments were non significant (F= 5.11; df= 2, 6; P < 0.01) at 70 DAS (Table I).

Overall, seasonal mean population of whitefly per leaf was maximum in untreated check (7.1) followed by thiamethoxam (6.3) and imidacloprid (5.1) during 2003. It was also recorded higher in untreated check (5.9) followed by thiamethoxam (4.4) and imidacloprid (3.7) during 2004. Similar trend in the whitefly population was recorded during 2005 and it was maximum in untreated check (6.7) followed by thiamethoxam (5.7) and imidacloprid (4.6) (Table II).

Table II.- Pool population of *B. tabaci* per leaf per year during 2003-05.

Seed treatment	Population per leaf (year wise)		
	2003	2004	2005
Imidacloprid	5.1	3.7	4.6
Thiamethoxam	6.3	4.4	5.7
Untreated	7.1	5.9	6.7
LSD 5%	**0.93**	**0.77**	**0.69**

Effect on parasitism

Three species of aphelinid parasites were identified, *Encarsia lutea* (Masi), *E. sophia* and *Eretmocerus mundus* Mercet, as parasitoids of *B. tabaci*.

During 2003, percent parasitism was significantly higher (F= 215.46; df= 2, 6; P < 0.01) in untreated check (72.4) followed by thiamethoxam seed treated plot (67.3) and significantly lowest in imidacloprid seed treated plot (65.8) at 30 DAS collected leaves. It was recorded significantly higher (F= 11.32; df= 2, 6; P < 0.01) in untreated plots compared with both the seed treated treatments plots collected leaves, but the percent parasitism in the imidacloprid and thiamethoxam seed treatments were non significant at 40 DAS. Similarly, the percent parasitism was significantly higher in untreated check plot at 50 DAS (F= 206.37; df= 2, 6; P < 0.01) and at 60 DAS (F= 141.74; df= 2, 6; P<0.01) compared with both seed treatments and percent parasitism difference within thiamethoxam and imidacloprid seed treatments were also significant during the same period. Level of parasitism were non significant (F= 1.55; df= 2, 6; P<0.01) in the seed treated and untreated check plots at 70 DAS collected leaves (Table III).

Table III.- Percent parasitism recorded during 2003 – 2005.

Treatments	Days after sowing (DAS)				
	30	40	50	60	70
2003					
Imidacloprid	65.8	72.1	31.7	14.8	37.8
Thiamethoxam	67.3	74.1	38.4	20.2	39.3
Untreated	72.4	77.2	40.2	24.5	38.2
LSD (5%)	**0.82**	**2.16**	**1.08**	**1.41**	**2.16**
2004					
Imidacloprid	35.3	55.7	75.0	44.0	28.7
Thiamethoxam	34.3	71.0	79.7	44.0	34.3
Untreated	42.1	81.7	90.5	49.5	49.5
LSD (5%)	**1.41**	**2.90**	**2.16**	**2.58**	**2.64**
2005					
Imidacloprid	65.1	83.3	50.0	67.2	69.3
Thiamethoxam	68.3	86.8	55.6	68.7	70.4
Untreated	77.1	93.7	86.1	92.4	79.5
LSD (5%)	**3.26**	**3.35**	**5.25**	**4.20**	**9.37**

During 2004, initially the level of parasitism was low compared with 2003 and afterward gradually increased in all the treatments. Level of parasitism was significantly higher (F= 108.08; df= 2, 6; P < 0.01) in untreated check compared with seed treated plots and the difference in the imidacloprid and thiamethoxam treated plots were non significant at 30 DAS. It was again significantly higher in untreated plots (F= 243.18; df= 2, 6; P < 0.01) compared with seed treated treatments at 40 DAS, but the difference within the seed treatments were significant and percent parasitism were significantly lower in imidacloprid plots. During 50 DAS, the similar trend in the parasitism was recorded and the parasitism was significantly higher in untreated plots (F=162.42; df= 2, 6; P < 0.01) compared with seed treated plots and the difference within the imidacloprid and thiamethoxam was also significant. Percent parasitism was significantly higher (F= 18.15; df= 2, 6; P<0.01) in untreated check compared with imidacloprid and thiamethoxam treated plots at 60 DAS, but the difference within the seed treatment insecticides were non significant. During 70 DAS, the difference within the treatments were significant (F= 198.58; df= 2, 6; P < 0.01) and highest parasitism was recorded in untreated check plot (49.5) followed by thiamethoxam (34.3) and imidacloprid (28.7) respectively (Table III).

During 2005, percent parasitism was significantly higher (F= 43.44; df= 2, 6; P < 0.01) in untreated check (77.1) compared with thiamethoxam seed treated plots (68.3) and imidacloprid seed treated plots (65.1) but the difference within the seed treated insecticides was non significant at 30 DAS. It was recorded significantly higher (F= 29.59; df= 2, 6; P < 0.01) in untreated plots compared with both the seed treated treatments plots, but the percent parasitism in the imidacloprid and thiamethoxam seed treatments were non significant at 40 DAS. Similarly, the percent parasitism was significantly higher in untreated check plot at 50 DAS (F= 166.64; df= 2, 6; P < 0.01) and at 60 DAS (F= 152.85; df= 2, 6; P < 0.01) compared with both seed treatments and percent parasitism difference within thiamethoxam and imidacloprid seed treatments were non significant during the same period. Level of parasitism were non significant (F= 4.27; df= 2, 6; P < 0.01) in the seed treated and untreated check plots at 70 DAS collected leaves (Table III)

Overall, seasonal mean percent parasitism was maximum in untreated check (50.5) followed by thiamethoxam (47.9) and imidacloprid (44.4) during 2003. It was also recorded higher in untreated check (62.7) followed by thiamethoxam (52.7) and imidacloprid (47.7) during 2004. Similar trend in the percent parasitism was recorded during 2005 and it was maximum in untreated check (85.8) followed by thiamethoxam (69.9) and imidacloprid (66.9) (Table IV).

Table IV. Pool percent parasitism per leaf per year during 2003-05.

Seed treatment	Percent parasitism (year wise)		
	2003	2004	2005
Imidacloprid	44.4	47.7	66.9
Thiamethoxam	47.9	52.7	69.9
Untreated	50.5	62.7	85.8
LSD (5%)	**0.82**	**1.18**	**1.49**

DISCUSSION

The prime objective of the study was to assess the effect of seed treatment insecticides imidacloprid and thiamethoxam against whitefly and its parasitoids. Early in the cotton season the population of whitefly remained below ETL level in all the treatments including the untreated check plots and gradually increased irrespective of treatments. Seed treatment insecticides gave significant control up to 50 to 60 DAS compared to the untreated check. Overall, seed treated with imidacloprid gave better control of whitefly compared with thiamethoxam and untreated check. Similarly, study undertaken by Torres and Ruberson (2004) revealed that thiamethoxam and imidacloprid showed significant control of whitefly in comparison with untreated plots upto 40 DAS. Percentage parasitism in the plots treated with imidacloprid and thiamethoxam was significantly lower than the untreated plots. During 2003, the percentage reduction in the imidacloprid treated plots were between 3.8 to 39.6% whereas, it was between 2.5 to 17.6% in thiamethoxam treated plots compared with untreated plots. During 2004, percentage parasitism reduction between 11.1 to 42.0% in imidacloprid and 11.1 to 30.7% in thiamethoxam was recorded. During 2005, reduction in parasitism between 11.1 to 41.9% in imidacloprid and 7.4 to 35.4% in thiamethoxam plots were recorded. Overall, percentage parasitism reduction in imidacloprid (19.2) was more than thiamethoxam (13.2) and control plots. A consistently lower reduction in percentage parasitism was observed in the thiamethoxam-treated plots compared to the imidacloprid-treated plots, thus suggesting a more toxic effect of imidacloprid to parasitoids than thiamethoxam.

Very few studies had been conducted on the systemic effect of neonicotinoids on the level of parasitism of *B. tabaci*. Study undertaken by Ogata (1999) and Torres *et al.* (2003) reported slight to moderate toxicity of thiamethoxam to parasitized whitefly pupae. In another study, Baldson *et al.* (1993) reported no effect of imidacloprid and thiamethoxam on emergence of *Anagrus takeyanus* Gordh, an egg parasitoid of the azalea lace bug *Stephanitis pyrioides* (Scott).

This study indicates that systemic insecticides applied in soil may be less harmful to parasitoids because direct contact is less. Although a direct comparison to foliar sprays was not made in the current study, a previous study suggests that the use of foliar spray early in the season not only disturbs the natural enemies but also flare up the sucking pest especially the *B. tabaci* (Naveed, 2006).

Integrated pest management practice in cotton production recommends the preservation of beneficial insects for control of various insect pests. Emphasis on IPM is especially important in early season cotton, when beneficials are capable of maintaining some pests below economic thresholds (Gerling, 1996; Gerling *et al*., 1997; Naranjo and Hagler, 1998; Naranjo *et al*., 1997). Consequently, the preservation of parasitoids activity is of great importance for *B. tabaci* management in the early stage of the crop. Information on the toxicities and exposure (foliar or systemic) of various cotton insecticides to several key beneficial species is therefore important in selection of compounds that will minimize mortality of these species. The knowledge gain from these experiments can be utilized to develop more effective pest management programs for early sucking pest.

ACKNOWLEDGEMENTS

The authors would like to acknowledge Professor Jian Huang, Director, College of Plant Protection, Fujian Agriculture and Forestory University, Fuzhou, Fujian, People’s Republic of China for identification of parasitoid samples and for providing technical information.

REFERENCES

ALMAND, L.K., 1995. Gaucho seed treatment for protection against early season insects. *Proc. Beltwide Cotton Conf. Memphis, Tenn.,* **2**: 1063-1065.

BALDSON, J.A., BRAMAM, S.K., PENDLEY, A.F. AND ESPELIE, K.E., 1993. Potential for integration on chemical and natural enemy suppression of azalea lace bug (Heteroptera: Tingidae). *J. environ. Hortic.,* **11**: 153-156.

BRADLEY, J.R.-JR., LAMBERT, A.L., SUH, C.P.C. AND FAIRCLOTH, J., 1998. Thrips management with Gaucho seed treatment in North Carolina cotton. *Proc. Beltwide Cotton Conf. Memphis, Tenn.,* **2**: 1183-1187.

BURD, J.D., ELLIOTT, N.C. AND REED, D. K., 1996. Effect of the aphicides 'Gaucho' and CGA-215944 on feeding behavior and tritrophic interactions of Russian wheat aphids. *Southwest. Ent.,* **21**: 145-152.

ELLSWORTH, P.C., DIEHL, J.W., DENNEHY, T.J. AND NARANJO, S.E., 1995. Sampling sweetpotato whiteflies in cotton, IPM Series No. 2. *The University of Arizona, Cooperative Extension, Publication #194023, Tucson.,* AZ, 2pp.

GERLING, D., 1996. Status of *Bemisia tabaci* in the Mediterranean countries: opportunities for biological control. *Biol. Contr.,* **6**: 11-22.

GERLING, D., KRAVCHENKO, V. AND LAZARE, M., 1997. Dynamics of common green lacewing (Neuroptera: Chrysopidae) in Israeli cotton fields in relation to whitefly (Homoptera: Aleyrodidae) populations. *Environ. Ent.,* **26**: 815-827.

GOBEL, T., GSELL, L. AND HUTER, O., 1999. Synthetic approaches towards CGA 293343: A novel broad-spectrum insecticide. *Pestic. Sci.,* **55**: 355-357.

GOMEZ, K.A. AND ARTURO, A.G., 1984. *Statistical procedures for agricultural research*. 2nd edition. John Wiley and Sons.

GRAHAM, C.T., 1998. Performance of Gaucho seed treatment across the mid-south and southeast. *Proc. Beltwide Cotton Conf. Memphis, Tenn.,* **2**: 1187-1188.

GRAHAM, C.T., JOHNIE, N.J. AND MCCARTY, J.C., 1995. Performance of Gaucho seed treatment insecticide against early season cotton insect pests. *Proc. Beltwide Cotton Conf. Memphis. Tenn.,* pp. 917-918.

HARVEY, T. L., SEIFERS, D. L. AND KOFOID, K. D., 1996. Effect of sorghum hybrid and imidacloprid seed treatment on infestations by corn leaf aphid and greenbug and the spread of sugarcane mosaic virus strain MDMV-B. *J. agric. Ent.,* **13**: 9-15.

HERNANDEZ, D., MANSANET, V., PUIGGROC, T. AND JOVE, J.M., 1999. Use of Confidor 200SL in vegetable cultivation in Spain. *Pflanzenschutz-Nachri. Bayer,* **52**: 364–375.

HOFER, D. AND BRANDL, F., 1999. Cruiser/Cruiser performance features of thiamethoxam as a seed treatment in worldwide cotton. *Proc. Beltwide Cotton Conf. Memphis, Tenn.,* **2**: 1101-1104.

KAGABU, S., 1999. Studies on the synthesis and insecticidal activity of neonicotinoid compounds. *Pestici. Sci.,* **21**: 231–239.

KERNS, D.L. AND PALUMBO, J.C., 1995. Using Admire on desert vegetable crops. Univ. Arizona IPM Series No.4, *The University of Arizona, Cooperative Extension. Publication # 195017,* Tucson, AZ, pp. 4.

LAWSON, D.S., DUNBAR, D.M., WHITE, S.M. AND NGO, N., 1999. Actara 25 WG: control of cotton pests with a new neonicotinoid insecticide, thiamethoxam. *Proc. Beltwide Cotton Conf. Memphis, Tenn.,* **2**: 1106-1109.

MAIENFISCH, P., BRANDL, F., KOBEL, W., RINDLISBACHER, A. AND SENN, R., 1999. CGA293'343: a novel, broad-spectrum neonicotinoid insecticide. In: *Nicotinoid insecticides and the nicotinic acetylcholine receptor* (eds. I. Yamamoto, J.E. Casdia),. Springer, Tokyo, pp. 177–209.

MAIENFISCH, P., HUERLIMANN, H., RINDLISBACHER, A., GSELL, L., DETTWILER, H., HAETTENSCHWILER, J., SIEGER, E. AND WALTI, M., 2001. The discovery of thiamethoxam: a second-generation neonicotinoid. *Pestic. Sci.,* **57**: 165–176.

MCKIRDY, S. AND JONES, R., 1996. Use of imidacloprid and newer generation synthetic pyrethroids to control the spread of barley yellow dwarf luteovirus in cereals. *Plant Dis.,* **80**: 895-901.

NARANJO, S.E., DIEHL, J.W. AND ELLSWORTH, P.C., 1997. Sampling whiteflies in cotton: validation and analysis of enumerative and binomial plans. *Environ. Ent.,* **26**: 777–788.

NARANJO, S.E., FLINT, H.M. AND HENNEBERRY, T.J., 1996. Binomial sampling plans for estimating and classifying population density of adult *Bemisia tabaci* on cotton. *Ent. Exp. Appl.,* **80**: 343–353.

NARANJO, S. E. AND HAGLER, J. R., 1998. Characterizing and estimating the impact of heteropteran predation. In: *Predatory Heteroptera: Their Ecology and use in biological control* (eds. M. Coll and J. Buberson). Thomas Say Symposium Proceedings. Entomological Society of America, Lanham, Maryland, pp. 170-197.

NAVEED, M., 2006. *Management strategies for* Bemisia tabaci *(Gennadius) on cotton in the Punjab, Pakistan*. Ph.D. thesis*.* Bahauddin Zakria University, Multan.

NAVEED, M., SALAM, A. AND SALEEM, M.A., 2007. Contribution of cultivated crops, vegetables, weeds and ornamental plants in harboring of *Bemisia tabaci* (Homoptera: Aleyrodidae) and associated parasitoids (Hymenoptera: Aphelinidae) in cotton agroecosystem in Pakistan. *J. Pest Sci.,* **80**: 191-197.

OGATA, Y., 1999. Integration of biological control and chemical control in case of Japan. *IOBC Bull.,* **22**: 189-191.

TORRES, J.B. AND RUBERSON, J.R., 2004. Toxicity of thiamethoxam and imidacloprid to *Podisus nigrispinus* (Dallas) (Heteroptera: Pentatomidae) nymphs associated to aphid and whitefly control in cotton. *Neotrop. Ent.,* **33**: 1-10.

TORRES, J.B., SILVA-TORRES, C.S.A. AND OLIVEIRA, J.V., 2003. Toxicity of pymetrozine and thiamethoxam to *Aphelinus gossypii* and *Delphastus pusillus*. *Pesq. Agropec. Bras.,* **38**: 459-466.

WILDE, G., ROOZEBOOM, K. AND CLAASSEN, M., 1999. Does the systemic insecticide imidacloprid (Gaucho) have a direct effect on yield of grain sorghum. *J. Prod. Ag.,* **12**: 382-389.

WOOLWEBER, D. AND TIETJEN, K., 1999. Chloronicotinyl insecticides: a success of the new chemistry. In:

Nicotinoid insecticides and the nicotinic acetylcholine receptor (eds. I. Yamamoto and J.E. Casdia). Springer, Tokyo, pp. 109–126.

YAMADA, T., TAKAHASHI, H. AND HATANO, R., 1999. A novel insecticide, acetamiprid. In: *Nicotinoid insecticides and the nicotinic acetylcholine receptor* (eds. I. Yamamoto and J.E. Casdia). Springer, Tokyo, pp. 149–176.

ZANG, L., MORTON, V. AND NGO, N., 1998. Cruiser: a new cotton insecticide seed treatment from Novartis crop protection. *Proc. Beltwide Cotton Conf. Memphis, Tenn.,* **2**: 1188-1190.

(Received 15 December 2009, revised 6 March 2010)