INTERNATIONAL JOURNAL OF AGRICULTURE & BIOLOGY
ISSN Print: 1560–8530; ISSN Online: 1814–9596
14–236/2015/17–3–483–490
DOI: 10.17957/IJAB/17.3.14.236
http://www.fspublishers.org

Full Length Article

Evaluation of Different Integrated Pest Management Modules to Control Helicoverpa for Adaptation to Climate Change

Muhammad Noor-ul-Ane*[1], Muhammad Jalal Arif[1], Muhammad Dildar Gogi[1] and Muhammad Aslam Khan[2]
[1]*Department of Entomology, University of Agriculture, Faisalabad, Punjab, Pakistan*
[2]*Department of Plant Pathology, University of Agriculture, Faisalabad, Punjab, Pakistan*
*For correspondence: mnoor493@hotmail.com

Abstract

The study was designed to investigate the impact of water stress on varietal response to cotton cultivars, *Helicoverpa armigera* and its associated entomophagous insects [*Chrysoperla carnea* (Stephens) and *Habrobracon hebetor* (Say)] as well as the feasibility of different Integrated Pest Management (IPM) modules for management of *H. armigera*. For this purpose, five drought resistant cotton genotypes i.e., FH-941, FH-187, FH-4243, FH-1000 and FH-207 were sown under irrigated and drought conditions. Larval population of *H. armigera* was low on water stressed plants (0.32 larvae/plant) as compared to irrigated plants (0.45 larvae/plant). In contrast, *H. armigea* caused more damage to stressed plants (16.90%) than irrigated plants (14.58%). FH-4243 was evaluated as resistant genotypes on the basis of less percent damage by *H. armigera* for both irrigated and drought conditions with value of 13.24 and 09.59%, respectively. Population of *C. carnea* was statistically similar under both for irrigated (0.20 larvae/plant) and drought conditions (0.19 larvae/plant). Unlikely, low parasitism of *H. armigera* by *H. hebetor* was observed under drought (14.64%) than irrigated condition (20.79%). Treatment involving integration of Neemosal, *C. carnea* and *H. hebetor* demonstrated 0.09 larvae/plant and provided maximum control of *H. armigera*; whereas alone application of Neemosal proved least effective against *H. armigera* (0.32 larvae/plant). On the basis of cost benefit ratio (CBR), module-15 involving integrated implementation of Spinosad, Neemosal, *C. carnea* and *H. hebetor* explained highest yield (1639.52 kg/ha) and CBR (1: 6.15) and proved economical and effective IPM module. In conclusion, water stress condition had positive impact on *H. armigera* feeding-damage (bi-trophic interaction) but had negative impact on parasitism. Integration of bio-control agents, botanicals and reduced-risk insecticides would be more cost-effective than their alone or two-level integration.

Keywords: Climate change; *Helicovepa armigera*; *Chrysoperla carnea*; *Habrobracon hebetor;* IPM

Introduction

Cotton (*Gossypium hirsutum* L.), a white gold is an important and valuable fiber crop due to its role in the economy of Pakistan. Cotton products contribute 11 percent to the GDP of the national economy (Naqvi and Nausheen, 2008). It contributes 31 and 38% to the investment sector and employment respectively (Altaf, 2008). A large number of factors, including non judicious use of fertilizer, low yielding varieties, poor weed management and heavy insect pest attack have resulted into lower yield of cotton. A large number of insect pests (96) and mites attack on cotton crop (Hasnain *et al.*, 2009). But the most important yield limiting insect is *H. armigera,* which is distributed throughout the world (EPPO, 2006) and found on a wide range of host plants including cotton, tomato (*Lycopersicon esculentum*), alfalfa (*Medicago sativa*) etc. due to its polyphagous nature (Deuter *et al.,* 2000). The young larvae of *H. armigera* attack on squares and flowers of cotton. While, mature larvae feed on green mature cotton bolls causing them to drop off from the plant and the holes due to damage of *H. armigera* can be seen at the base of cotton bolls. Approximately, 30% yield losses due to damage of *H. armigera* have been recorded (Yazdanpanah *et al*., 2009).

Importance of plant and insect interaction is established in relation to their role on ecology and functioning of ecosystems (Johnson, 2011). Therefore, a joint response between plant and insect towards climate change must be established (Walters, 2011). Climate change consequence will be a rise in mean temperature with range of 1.4 to 5.8°C by the end of coming century and increased drought frequency (IPCC, 2001). Drought is an abiotic stress which results due to insufficient rainfall for a long period of time in a particular area. This shortage of water may decrease soil moisture to extent that normal growth of plants is impeded (Akhtar and Nazir, 2012) resulting low crop production (Vincent *et al*., 2005). Various authors have hypothesized that increased drought linked

To cite this paper: Noor-ul-Ane, M., M.J. Arif, M.D. Gogi and M.A. Khan, 2015. Evaluation of different integrated pest management modules to control helicoverpa for adaptation to climate change. *Int. J. Agric. Biol*., 17: 483–490

with climate warming could increase insect outbreak (Trumble and Butler, 2009; Karuppaiah and Sujayanad, 2012), which in return could be synergistic to drastic impacts of drought on plants (Hale *et al*., 2005). Drought alters plant physiology, in particular nitrogen availability, and these changes encourage more herbivore damage on these plants. This hypothesis is termed as Plant Stress Hypothesis (White, 1969). But, there is another conflicting theory, 'Plant Vigor Hypothesis' which postulates that insects prefer to feed on vigorously growing plants (Price, 1991) rather to feed on stressed plants as these plants have low nutritive content due to reduced water uptake (Daane and Williams, 2003). These clashing theories are real hurdle to the predict response of species in context to climate change. It is therefore, needed to establish environment under which accuracy of these theories towards their predictions can be increased and how different plant genotypes respond to pest and natural enemies (predators, parasitoids) under water stress. Moreover, identifying germplasm, those have resistance both for abiotic and biotic stress can serve breeders to develop new varieties that can be used as an adaptation to climate change (Manavalan *et al*., 2009).

Resistant varieties, use of chemicals and biological control agents are strategies to control insect pests of many crops including cotton (Bull *et al.,* 1979). Chemical control is the most widely used to keep cotton pests under economic thresholds. An indiscriminate use of chemicals caused a heavy outbreak of cotton bollworm (Ahmad *et al.,* 1997). *Helicoverpa armigera* showed a high level of resistance to monocrotophos and low level of resistance to chlorpyrifos and profenophos were reported from Pakistan (Ahmad *et al*., 1995). Pesticides can cause resistance to chemicals and pest resurgence. They are also a source of environmental pollution and have adverse impact on non-target organisms like natural enemies (Rumpf *et al.,* 1997). Heavy use of chemicals to control *H. armigera* has caused resistance development in this pest (Kranthi *et al.,* 2002). These findings suggest an urgent need for the development of bio-intensive Integrated Pest Management (IPM) to control notorious insect pests without harming the environment and human health. Implementation of control tactics in an integrated way gives an efficient control of *H. armigera* rather than individually (Tanweer and Rao, 1997).

This study was carried out to investigate: 1) the impact of water stress on varietal response to *H. armigera* and entomophagous insects [predator (*Chrysoperla carnea*) and parasitoid (*Habrobracon hebetor*)] and 2) the feasibility of different integrated pest management modules for management of *H. armigera*.

Materials and Methods

Impact of Water Stress on Varietal Response to *H. armigera* and its Associated Natural Enemies

Different drought tolerant cotton genotypes, i.e. FH-941, FH-187, FH-4243, FH-1000 and FH-207 (ARRI un-published data), were sown to evaluate their resistant response to *H. armigera* and its associated entomophagous insects under irrigated and non-irrigated conditions. The experiment was laid out in factorial Randomized Complete Block Design (RCBD). Sowing of cotton was done on 15th of May, 2012 by bed planting method. Plot size for each genotype was 6 × 15 m^2 where plat-to-plant and row-to-row distances of 75 cm were maintained. The beds were made with tractor mounted ridger and bed-furrow shaper. Sowing of delinted cotton seeds was done manually at field capcity condition with 2-3 seeds per hill. The beds were irrigated 3 days after sowing to ensure the germination of un-soaked delinted cotton seeds. After this, the plots specified for no-irrigation treatment (T_2) did not receive irrigation except post sowing irrigation for normal plant distribution. However, the plots specified for application of routine irrigation (T_1) were irrigated subsequently at fortnightly interval. The gaps, exhibiting failure of seed germination, were also filled by re-sowing of seeds manually to ensure required plant population. One month after germination, the plants population was thinned manually keeping required healthy plant population and discarding week plants from treatments. Scouting consisting of random visual inspection of 25 plants in each replication of each cotton genotypes was done on weekly basis. Routine weekly crop scouting was started from first week of July to last week of October to determine larval population of *H. armigera*, and *C. carnea* per plant as well as percent parasitism of *H. armigera* larvae by *H. hebetor*. For determining percent parasitism, larvae of *H. armigera* were collected from treatments, brought into IPM laboratory, Department of Entomology, University of Agriculture, Faisalabad, counted and placed in separate glass jars with cotton bolls as natural diet. The larvae killed by parasitoid or exhibiting the symptoms of parasitism (pupae of parasitoid on larval body) were counted and percent parasitism was calculated by the formula (1):

$$\text{Percent parasitism} = \frac{\text{Number of parasitized larvae}}{\text{Total number of larvae collected}} \times 100 \quad (1)$$

For determining percent damage on cotton genotypes by *H. armigera* in irrigated and non-irrigated plots, randomly damaged and undamaged bolls and fruits from randomly selected 25 plants were visually counted weekly and then this data were transformed into average percent damage, which was calculated by the formula (2):

$$\text{Percentage Damage} = \frac{\text{Damaged fruiting bodies}}{\text{Total fruiting bodies}} \times 100 \quad (2)$$

The data regarding population of *H. armigera*, *C. carnea*, percent parasitism and percent damage were subjected to two way factorial analysis for determining difference in treatments and means of significant treatments

were compared by Tukey's Honest Significant Difference (HSD) test at P≤0.05.

Integration of Various Control Methods for Management of *H. armigera*

Integrated pest management modules were evaluated against cotton bollworm, *H. armigera* at two different locations i.e., a farmer's field near Postgraduate Agricultural Research Station (PARS), University of Agriculture Faisalabad and a farmer's field near Chack Jhumra, Faisalabad. This area is in the central mixed zone in the agro-ecological zones of Punjab. Faisalabad is situated at the rolling flat plane of the North East of the Punjab. This region is almost at the plain level, about 186.54 m above sea level. The longitude 73°, 74° while latitude 30-31.5°North. The average yearly rainfall is (400 mm) and it occurs around the months of July and August. Cotton, FH-4243 (screened *H. armigera* resistant genotype), was sown on 15 May, 2013 in a farmer's field near PARS and 17 May, 2013 in the farmer's field at Chack Jhumra in a Randomize Complete Block Design (RCBD). There were three replications for each treatment. Plot size of each treatment was 9.1 m × 10.7 m in each locality, whereas row-to-row and plant-to-plant distance was maintained 0.85 m and 0.20 m, respectively. Twenty five plants were randomly selected for *H. armigera* population from each treatment and yield was also calculated for each treatment. Dose of Spinosad, neem seed kernel extract (Neemosal), *C. carnea* and *H. hebetor* was 200 mL/ha, 1500 mL/ha, 150 cards/ha (25-30 eggs/card), 100 capsules/ha (10 pupae/capsule), respectively. The number and detailed application of sprays/releases are mentioned in Table 1.

The data were statistically analyzed for analysis of variance by SPSS software and means were compared with Tukey's HSD test at P≤0.05. Cost Benefit Ratios (CBR) for each treatment was calculated as follows (Aurangzeb *et al*., 2007; Zia, 2011):

Results

Impact of Water Stress on Varietal Response to *H. armigera* and its Associated Natural Enemies

Larval population of *H. armigera* significantly varied among treatments (F=124.1, DF=1 and P<0.001) and genotypes (F=18.75, DF=4 and P<0.001) but the interaction between genotypes and treatment was not significant (F=1.14 DF=4 and P>0.05) larvae/plant. Minimum population of *H. armigera* was recorded on the genotype FH-4243 with value of 0.31 larvae/plant. While, FH-1000 had maximum population of *H. armigera* (0.45 larvae/plant) which was statistically at par with FH-207 (0.41 larvae/plant). The population of *H. armigera* was lower on cotton plants growing under drought conditions (0.32 larvae/plant) as compared to the plants growing under irrigation (0.45 larvae/plant). Damage caused by *H. armigera* was significantly different (F= 247.09, DF= 1 and P<0.001) in treatments (irrigated vs drought) and among genotypes (F= 500.28, DF= 4 and P<0.001) but the interaction between genotype and treatment was significant (F= 130.18, DF= 4 and P<0.001) (Table 2). Maximum damage was recorded on genotype, FH-207, at a value of 22.45%, which was followed by FH-1000 for both irrigated (18.73%) and drought (20.92%) conditions. Minimum damage was recorded in genotype, FH-4243, both under irrigated (13.24%) and drought (09.59%) conditions. The percentage damage of 17.04 and 14.50 was recorded on the genotypes FH-941 and FH-187, respectively under drought condition. Overall, high damage (17.63%) was recorded on plants growing under drought conditions as compared to those under irrigated conditions (13.85%). The damage irrespective to treatments was recorded with values of 11.41, 12.97, 15.42, 19.08 and 19.83% on genotypes FH-4243, FH-187, FH-941, FH-207, FH-1000, respectively (Table 2).

C. carnea population was significantly (F=8.5, DF=4 and P<0.001) different among the genotypes but not significant between the treatments (irrigated and drought) (F=2.01, DF=4 and P>0.05) and their interaction (F=0.63, DF=4 and P>0.05). Population of *C. carnea* was not significantly different between drought (0.19 larvae/plant) and irrigated (0.20 larvae/plant) condition. Population of *C. carnea* was recorded maximum on genotypes FH-207 and FH-1000 with same values of 0.22 larvae/plant, which were not statistically significant with genotypes FH-941 (0.19 larvae/plant) and FH-187 (0.19 larvae/plant). While, low population of *C. carnea* (0.15 larvae/plant) was observed on FH-4243. Analysis of variance showed that parasitism was highly significant for genotypes (F=27.19, DF=4 and P<0.001) and treatments (F=85.71, DF=4 and P<0.001) but not for the genotype x treatment interaction (F=1.05, DF=4 and P>0.05). Parasitism was significantly reduced to the value of 14.64% on cotton genotypes cultivated under drought condition as compared to irrigated condition with 20.79% (Table 2). Maximum parasitization of *H. armigera* by *H. hebetor* was recorded in genotype, FH- 207 with value of 22.17%, which was followed by FH-1000 (19.92%), FH-941 (18.62%) and FH-187 (15.63%). In contrast, minimum parasitism (12.22%) was recorded on genotype, FH-4243.

Evaluation of Integrated Pest Management Modules

The population of *H. armigera* was significantly (F= 44.26, DF = 15 and P≤ 0.01) differed in different treatments used in this study (Table 3). Larval population of *H. armigera* was recorded at 0.25, 0.27, 0.30 and 0.32 per plant in T3, T1, T4 and T2, respectively. Maximum reduction in larval population of pest was recorded in T3 (*C. carnea*) over T1, T2 and T3, when control methods used singly. When *C. carnea* was combined with other control methods

Table 1: Treatment combinations, number of applications and details of application of sprays/releases used in treatments

Treatments		Number of applications of sprays/releases	Application details
T1	Spinosad (S)	10 sprays	Neemosal was applied when *H. armigera* population reached its ETL (3 larvae/eggs per 25 plants).
T2	Neemosal (N)	10 sprays	Spinosad was applied when *H. armigera* population reached its ETL (3 larvae/eggs per 25 plants).
T3	*C. carnea* (C)	10 releases	*Chrysoperla carnea* released fortnightly.
T4	*H. hebetor*(H)	05 releases	*Habrobracon hebetor* released fortnightly.
T1 + T2	S*N	05 sprays	Alternative sprays of Spinosad and Neemosal were applied on ETL of population.
T1 + T3	S*C	05 spray + 05 releases	Spinosad application was done at ETL of Population whereas the cards of *C. carnea* eggs were installed after 7 days of Spinosad spray.
T1 + T4	S*H	05 sprays + 03 releases	Spinosad was applied when population of *H. armigera* reached its ETL. The capsules of *H. hebetor* were installed after 7 days of Spinosad spray.
T2 + T3	N*C	05 sprays + 05 releases	Neemosal was applied when population of *H. armigera* reached its ETL. The cards of *C. carnea* eggs were installed after 7 days of Neemosal spray.
T2 + T4	N*H	05 sprays + 03 release	Neemosal application was done when population of *H. armigera* reached its ETL. The capsules of *H. hebetor* were installed after 7 days of Neemosal.
T3 + T4	C*H	05 sprays + 03 releases	The releases were started at the initiation of flowering stage and continued at an interval of seven days. After every two releases of *C. carnea*, one release of *H. hebetor* was carried out. This practice was carried out till the maturity of the crop.
T1 + T2 + T3	S*N*C	03 spray + 03 spray + 03 releases	Firstly, the spray of Spinosad was done when *H. armigera* reached its ETL. Second spray of Neemosal was applied when the population of *H. armigera* reach to its ETL. After 7 days of Neemosal application, release of *C. carnea* was made. This sequence of three practices was carried out till the maturity of the crop.
T1 + T2 + T4	S*N*H	03 spray + 03 spray + 03 releases	Firstly, the spray of Spinosad was done when *H. armigera* reached its ETL. Second spray of Neemosal was applied at ETL of *H. armigera*. After 7 days of Neemosal application, release of *H. hebetor* was made. This sequence of three practices was carried out till the maturity of the crop.
T1 + T3 + T4	S*C*H	03 spray + 03 spray + 03 releases	Firstly, the spray of Spinosad was done when *H. armigera* reached its ETL. After 7 days of Spinosad application, releases of *C. carnea* and *H. hebetor* was done simultaneously. Second spray of Spinosad was applied when *H. armigera* reach to its ETL again followed by releases of *C. carneaa* and *H. hebetor* 7 days of post application of Spinosad, simultaneously. This sequence of three practices was carried out till the maturity of the crop
T2 + T3 + T4	N*C*H	04 spray + 03 spray + 02 releases	Firstly, the spray of Neemosal was done when *H. armigera* reached its ETL. After 7 days of Spinosad application, releases of *C. carnea* and *H. hebetor* was done simultaneously. Second spray of Neemosal was applied when *H. armigera* reach to its ETL again followed by releases of *C. carnea* and *H. hebetor* 7 days post application of Neemosal, simultaneously. The releases of *H. hebetor* were not made for the third time. This sequence of three practices was carried out till the maturity of the crop.
T1 + T2 + T3 + T4	S*N*C*H	03 spray + 03 spray + 02 releases + 02 sprays	Firstly, the spray of Spinosad was done by when *H. armigera* reached its ETL. A spray of Neemosal was applied when *H. armigera* reach to its ETL again followed by releases of *C. carnea* and *H. hebetor* after 7 days of post application of Neemosal, simultaneously. This sequence of practices application was repeated again at ETL. Later on, when *H. armigera* reached ETL again, a spray of Spinosad and Neemosal was applied alternatively till the maturity of the crop.
Control		No control measures applied	

Table 2: Impact of drought on larval population and damage (%) caused by *H. armigera*, *C. carnea* and parasitism (%) of *H. armigera* by *H. hebetor*

Genotype	*H. armigera*/plant			Damage (%)			*C. carnea*/Plant			Parasitism (%)		
	Irrigated	Drought	Mean	Irrigated	Drought	Mean	Irrigated	Drought	Mean	Irrigated	Drought	Mean
FH-941	0.44	0.34	0.39 bc	13.79 fg	17.04 d	15.42 c	0.26	0.18	0.19 ab	20.60	16.63	18.62 b
FH-187	0.43	0.30	0.36 c	11.44 h	14.50 f	12.97 d	0.24	0.18	0.19 b	18.56	12.70	15.63 c
FH-4243	0.39	0.22	0.31 d	13.24 g	09.59 i	11.41 e	0.19	0.15	0.15 c	15.14	09.30	12.22 d
FH-1000	0.49	0.40	0.45 a	18.73 c	20.92 b	19.83 a	0.30	0.21	0.22 a	23.46	16.39	19.92 b
FH-207	0.47	0.35	0.41 ab	15.72 e	22.45 a	19.08 b	0.29	0.23	0.22 a	26.19	18.15	22.17 a
Mean	0.45 a	0.32 b		14.58 b	16.90 a		0.20 a	0.19 a		20.79 a	14.64 b	
	LSD			LSD			LSD			LSD		
Genotypes	0.04**			0.70**			0.03**			2.21**		
Treatment	0.02**			0.31**			NS			1.40**		
Genotypes X Treatment	NS			1.18			NS			NS		

Means sharing similar letters in the same column are not significantly different by Tukey's HSD test at P= 0.05. **= Highly significant at P < 0.01 NS= Non-Significant at P>0.05. Genotypes means are compared column wise, treatments means are compared by row wise and interaction is row x column wise

it gave better control against *H. armigera* as compared with individual treatment. *H. hebetor* reduced population to 0.09/plant in combination with Neemosal and *C. carnea,* which was followed by T13 (0.10/plant), T12 (0.14/plant), T10 (0.17/plant), T7 (0.22/plant) and T9 (0.19/plant) as compared to single application. Application of Neemosal reduced population of *H. armigera* with a value of 0.32/plant over control (0.50/plant). When neem in combination of other control methods was used, the population of *H. armigera* was further reduced as compared

to single application. Neemosal spray was more effective when combined with Spinosad application with a value of 0.20/plant as compared with the combined application of

Table 3: *Helicoverpa armigera* population and cost benefit ratio in different treatments

Treatments	*H. armigera*/plant	CBR
Spinosad (S)	0.27 bc	1:6.40
Neemosal (N)	0.32 b	1:2.26
C. carnea (C)	0.25 cd	1:2.79
H. hebetor(H)	0.30 bc	1:3.07
S*N	0.20 bcd	1:6.24
S*C	0.19 def	1:4.77
S*H	0.19 de	1:5.59
N*C	0.22 cd	1:3.94
N*H	0.22 cd	1:4.61
C*H	0.17 def	1:2.88
S*N*C	0.12 efg	1:5.79
S*N*H	0.14 efg	1:5.95
S*C*H	0.10 fg	1:4.97
N*C*H	0.09 g	1:4.75
S*N*C*H	0.12 efg	1:6.15
Control	0.50 a	

Means sharing similar letters in the same column are not significantly different by Tukey's HSD test at P= 0.05

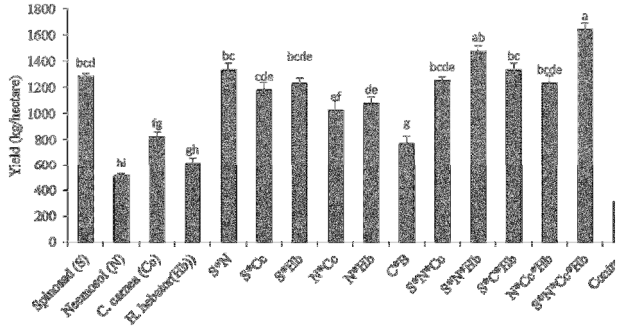

Fig. 1: Marketable yield (kg/ha) in different treatments

biological control agents (0.22/plant). Application of Spinosad also significantly reduced *H. armigera* population (0.27/plant) further than the control. Population of *H. armigera* was recorded with the values of 0.19, 0.19 and 0.20/plant in T7, T6 and T5, respectively. This suggests that Spinosad is more effective with combination of biological control agents than combination of Neemosal.

Overall comparison of treatments showed that T14 (Neemosal + *C. carnea*+ *H. hebetor*) reduced maximum population of *H. armigera* with a value of 0.09/plant, which was followed by T13 i.e., Spinosad + *C. carnea* + *H. hebetor* (0.1/plant), T11 i.e., Spinosad + Neemosal + *C. carnea* (0.12/plant), T15 i.e., Spinosad + Neemosal + *C. carnea* + *H. hebetor* (0.12/plant) and T12 i.e., Spinosad + Neemosal + *H. hebetor* (0.14/plant). Population of *H. armigera* was recorded 0.22/ plant in T8 (Neemosal and *C. carnea*), which was statistically at par with T9 (Neemosal and *H. hebtor*).

Analysis of variance showed significant (F= 58.67, DF= 15 and P $\leq$ 0.001) difference among treatments regarding seed cotton yield (Fig. 1). The maximum yield was recorded 1639.52 kg/ha (16.0 kg/plot) in T15 [T1 (spray of Spinosad) + T2 (spray of Neemosal) + T3 (release of *C. carnea*) + T4 (release of *H. hebetor*)], which was followed by T12 [T1 (spray of Spinosad) + T2 (spray of Neemosal) + T4 (releases of *H. hebetor*)] and T13 [T1 (spray of Spinosad)+ T3 (release of *C. carnea*) + T4 (release of *H. hebeor*)] with values of 1475.568 and 1332.11 kg/ha, respectively. Yield was recorded 12-12.5 kg/plot (1229.64-1280.875 kg/ha) in plots treated with T7 [T1 (sprays of Spinosad) + T4 (releases of *H. hebetor*)], T14 [T2 (spray of Neemosal) + T3 (release of *C. carnea*) + T4 (release *H. hebetor*)], T11 [T1 (spray of Spinosad) + T2 (spray of Neemosal) + T3 (releases of *C. carnea*)] and T1 (spray of Spinosad), which was statistically at par with each other.

Cost benefit ratio was calculated for all treatments and are presented in Table 3. Maximum cost benefit ratio was recorded with value of 1:6.4 and 1:6.2 in T1 (spray of Spinosad) and T15 [T1 (spray of Spinosad) + T2 (spray of Neemosal)], which was followed by 1:6.1, 1:5.95 in T15 [T1 (spray of Spinosad) + T2 (spray of Neemosal)+ T3 (release of *C. carnea*) + T4 (release of *H. hebetor*)] and T12 [T1 (spray of Spinosad) + T2 (spray of Neemosal) + T4 (releases of *H. hebetor*)], respectively. Cost benefit ratio with values of 1:5.79, 1:4.97 and 1:4.75 were calculated in T11 [T1 (spray of Spinosad) + T2 (spray of Neemosal) + T3 (releases of *C. carnea*)], T13 [T1 (spray of Spinosad) + T3 (release of *C. carnea*) + T4 (release of *H. hebeor*)] and T14 [T2 (spray of Neemosal) + T3 (release of *C. carnea*) + T4 (release *H. hebetor*)], respectively. Minimum cost benefit ratio was calculated 1:2.26 in T2 (releases of Neemosal). The results showed that T15 [T1 (spray of Spinosad) + T2 (spray of Neemosal) + T3 (release of *C. carnea*) + T4 (release of *H. hebetor*)] is most suitable combination of control method for eco-friendly management of *H. armigera*.

Discussion

Insect behaviour (development and reproduction) vary greatly with physio-chemical changes that occur in water-stressed plants (Mattson and Haack, 1991). The present study results showed maximum population of *H. armigera* was recorded on genotypes cultivated under irrigated condition (0.44 larvae/plant) as compared to those growing under drought condition (0.32 larvae/plant). Survival of insect is lower on stressed plants than irrigated plants (Showler and Moran, 2003) a scenario that was well shown in our study. This poor performance of bollworm may be due to reduced nitrogen availability (McMillin and Wagner, 1995) or elevated allelochemicals (Inbar *et al*., 2001) on stressed plants. High larval mortality of fall armyworm has also been reported on dry land soybean than on irrigated soybean (Huffman and Mueller, 1983). Similarly, larvae of beet armyworm resulted in reduced growth when reared on water-stressed tomato plant (English-Loeb *et al*., 1997).

In our study, percent damage caused by *H. armigera* was high in drought treated plants than irrigated plants even with low population of *H. armigera*. This result confirms the prediction that plants can have more insect damage under drought (Paritsis and Veblen, 2011) because water stress promotes the accumulation of free amino acids in plants which favour the development of insects (Showler, 2012). These can be more attractant to herbivore as insects use nitrogen from gut in form of amino acids (Brodbeck and Strong, 1987). Sugarcane varieties are more susceptible to *Sipha flava* (Forbes), if they have high concentration of essential amino acids (Akbar *et al*., 2010).

There was a significant interaction of genotypes and drought against *H. Armigera.* Yadav *et al*. (2006) also reported resistant genotypes of chickpea both against *H. armigera* and drought. Similarly, significant interaction was found between drought and genotypes of soybean for herbivores (*Helicoverpa zea* and *Spodoptera exigua*) (Grinnan *et al*., 2013). Mao *et al*. (2004) also concluded that two genotypes of sweet potato had different response for sweet potato weevil feeding as well as its oviposition under drought condition. There is a need to identify genotypes that have resistance/tolerance against abiotic stress related to climate change (Sinclair, 2011). Identification of genotypes that have resistance both for abiotic (e.g., drought) and biotic stress (insect) may help the breeders to develop new varieties that could be cultivated in future climates (Long and Ort, 2010) and to find out mechanism involved for resistance both for abiotic and biotic stresses.

In present study, population of *C. carnea* was not-significant between drought and irrigated conditions. It may be due to reason that altered host quality of a single species may not influence behaviour of predator (Romo and Tylianakis, 2013). In contrast, predators like anthocorids have shown positive association with drought in corn crop (Godfrey *et al*., 1991). This difference may be due to behaviour of natural enemies like anthocorids also feed on plant parts at the time of low pest densities (Lundgren *et al*., 2008) and therefore can directly affect by water stressed plants. Our results show that parasitism of *H. armigera* was lower in water-stressed plant than irrigated plants. Similar behaviour of *Aphidius colemani* (Viereck) and *A. ervi* (Haliday) had been reported with drought (Tariq *et al*., 2013). Similarly, mango mealybug parasitism was recorded to be low under drought condition than irrigated condition (Calatayud *et al*., 2002). Fitness of natural enemies may indirectly affect due to change in prey qualities which are feeding on stressed plants therefore; drought can disturb prey-predator interaction. This multitrophic interaction also related with defensive compounds of plants. There is evidence that plant defensive compounds may alter foraging behaviour of parasitoids (Aslam *et al*., 2012).

Drought also increased phytotoxin concentration and accumulated in insects feed on that stressed plants and therefore, can accumulate in the body of their natural enemies and could influence fitness of natural enemies in terms of growth and development (Soler *et al*., 2012). Drought can influence the emission of volatile compounds (VOCs) in plants (Holopainen and Gershenzon, 2010) and which in return can affect foraging behaviour of natural enemies (Rasmann and Turlings, 2007).

Treatment with Spinosad and *H. hebetor* showed comparatively less larval population per plant (0.19 larvae/plant) than treatments with Spinosad + Neemosal (0.20 larvae/plant) but statistically at par with Spinosad + *C. carnea* (0.19 larvae/plant). Spinosad is safe for parasitoid, *Catolaccus grandis* (Burks) therefore can be combined with parasitoids to control the insect pests (Elzen *et al*., 2000). In contrast, parasitoids had been negatively affected by Spinosad (Williams *et al*., 2003). Parasitoids can recover within 1-2 weeks after application of Spinosad (Scholz *et al*., 2002). To ensure better results with this combination, there is a need to consider the persistence of Spinosad in relation to application and releases of the parasitoids (Miles and Dutton, 2000).

The maximum larval population after the control plot was recorded on the treatments with Neemosal alone and with combination of *C. carnea and H. hebetor* separately, suggesting that Neemosal is least effective in controlling the pest population, alone and in combination with *C. carnea* and *H. hebetor*. It can be compared with the findings that Neemosal failed to control cotton bollworm complex possibly due to lack of its contact action (Isman, 2004). High mortality of *C. carnea* larvae have been reported when placed on NeemAzal-T/S contaminated glass plates in laboratory experiments (Hermann *et al*., 1995), explained the possible cause of failure of Neemosal and *C. carnea* in combination. In contrast, there is evidence that botanical insecticides can effectively control the lepidopteron larvae (Koul *et al*., 2004). Various authors verified that neem extract is suitable to control different insect pests like *Cnaphalocrocis medinalis, Maruca vitrata,* including *H. armigera* in different cropping systems (Boomathi *et al*., 2006; Rouf and Sardar, 2011).

The treatment plot with Neemosal + *C. carnea* + *H. hebetor* had the lowest larval population among all treatments, but is not statistically different with bio-intensive IPM modules consisting of Spinosad + *C. carnea* + *H. hebetor*. Maximum larval population was found in the control plot. These results suggested that Neemosal + *C. carnea* + *H. hebetor*, is most effective treatments to control bollworm. Praveen (2000) reported that application of bio-intensive IPM module is very effective to control the *H. armigera*. Ravi *et al*. (2008) reported that HaNPV, Btk, azadirachtin and Spinosad were safe to natural enemies as in case of predatory mirids and spiders, agreeing with our results.

Minimum yield of 512.35 kg/ha and CBR value (1: 2.26) was recorded in Neemosal treated plot as compared with other treatment modules. Vogt *et al.* (1997) also reported low yield in the neem treated plot to control Dysaphis plantaginea (Passerini). In contrast, increase in

yield has been recorded when neem is applied to control pest (Tanzubil *et al*., 2008). The module consisting of T15, Spinosad + Neemosal + *C. carnea* + *H. hebetor* resulted in maximum yield of 1639.52 kg/ha with cost benefit ratio of 1: 6.15. Increase in yield was recorded with the treatment of *Ha*NPV, *Btk,* azadirachtin and Spinosad to suppress the population of *H. armigera* (Ravi *et al*., 2008). High cost benefit ratio was observed in IPM modules by various authors (Kaboré *et al*., 2002; Karabhantanal *et al*., 2005; Patel *et al*., 2009). Cherry *et al.* (2000) reported that cost of treatment is pre-requisite to select the treatment to control insect pests.

Conclusion

FH-4243 was determined as bollworm resistant genotype in the screening experiment. *H. armigera* caused more damage on drought stressed plants than irrigated plants hence it favours the theory of Plant Stress Hypothesis. Drought could not cause significant effect on population of *C. carnea* but caused detrimental effects on parasitism of *H. armigera* by *H. hebetor*. T15, Spinosad + Neemosal + *C. carnea* + *H. hebetor* was most eco-friendly IPM module with cost benefit ratio of 1: 6.15.

References

Ahmad, M., M.I. Arif and M.R. Attique, 1997. Pyrethroid resistance of *Helicoverpa armigera* (Hubner) (Lepidoptera: Noctuidae) in Pakistan. *Bull. Entomol. Res.*, 87: 343-347

Ahmad, M., M.I. Arif and Z. Ahmad, 1995. Monitoring of insecticide of *H. armigera* (Hübner) (Lepidoptera: Noctuidae) in Pakistan. *J. Econ. Entomol.*, 88: 771–776

Akbar, W., A.T. Showler, W.H. White and T.E. Reagan, 2010. Categorizing sugarcane cultivars for resistance to the sugarcane aphid and yellow sugarcane aphid (Hemiptera: Aphididae). *J. Econ. Entomol.*, 103: 1431–1437

Akhtar, I. and N. Nazir, 2012. Effect of Water logging and Drought Stress in Plants. *Int. J. Water Resour. Arid Environ*., 2: 169–175

Altaf, Z., 2008. Challenges in Pakistan cotton, yarn, textile and apparel sectors. *In*: *Cotton-textile-apparel Sectors of Pakistan: Situation and Challenges Faced*, p: 52. Cororaton, C.B., A. Salam, Z. Altaf and D. Orden (eds.). Cotton-Textile-Apparel sectors of Pakistan. IFPRI (International food Policy Research Institute) Discussion Paper 00800, Sept. 2008. International Food Policy Research Institute, Washington DC, USA

Aslam, T.J., S.N. Johnson and A.J. Karley, 2012. Plant-mediated effects of drought on aphid population structure and parasitoid attack. *J. Appl. Entomol.*, 137: 136–145

Aurangzeb, M., S. Nigar and M.K. Shah, 2007. Benefit cost analysis of the maize crop under mechanized and traditional farming systems in the NWFP. Sarhad *J. Agric.*, 23: 169–176

Boomathi, N., P. Sivasubramanian and S. Raguraman, 2006. Biological activities of cow excreta with neem seed kernel extract against *Helicoverpa armigera* (Hubner). *Ann. Plant Prot. Sci.,* 14: 11–16

Brodbeck, B. and D. Strong, 1987. Amino acid nutrition of herbivorous insects and stress to host plants. *In*: *Insect Outbreaks,* pp: 346–364. Barbosa, P. and J.C. Schultz (eds.). Acad. Press England

Bull, D.L., V.S. House, J.R. Ables and R.K. Morrison, 1979. Selective methods for managing insect pests of cotton. *J. Econ. Entomol.*, 72: 841–846

Calatayud, P.A., M.A. Polania, C.D. Seligmann and A.C. Bellotti, 2002. Influence of water-stressed cassava on *Phenacoccus herreni* and three associated parasitoids. *Entomol. Exp. Appl.*, 102: 163–175

Cherry, A.J., R.J. Rabindra, M.A. Parnell, N. Geetha, J.S. Kennedy and D. Grzywacz, 2000. Field evaluation of *Helicoverpa armigera* nucleopolyhedrovirus formulations for control of the chickpea pod-borer, *H. armigera* (Hubn.), on chickpea (*Cicer arietinum* var. Shoba) in southern India. *Crop Prot*., 19: 51–60

Daane, K.M. and L.E. Williams, 2003. Vineyard irrigation amounts to reduce insect pest damage. *Ecol. Appl*., 13: 1650–1666

Deuter, P., B. Nolan, T. Grundy and B. Walsh, 2000. *Heliothis in sweet corn. DPI note; File No: H0159.* Queensland Horticulture Institute, Gatton Research Station. URL: http://www.dpi.qld.gov.au/horticulture/5227.html

Elzen, G.W., S.N. Maldonad and M.G. Rojas, 2000. Lethal and sublethal effects of selected insecticides and an insect growth regulator on the boll weevil (Coleoptera: Curculionidae) ectoparasitoid *Catolaccus grandis* (Hymenoptera: Pteromalidae). *J. Econo. Entomol.*, 93: 300–303

English-Loeb, G., M.J. Stout and S.S. Duffey, 1997. Drought stress in tomatoes: Changes in plant chemistry and potential nonlinear consequences for insect herbivores. *Oikos*, 79: 456–468

EPPO, 2006. *Distribution maps of Quarantine Pests*. *Helicoverpa armigera*. On-line available at www.eppo.org/QUARANTINE/insects/Helicoverpa_armigera/HELIAR_map.htm

Godfrey, L.D., K.E. Godfrey, T.E. Hunt and S.M. Spomer, 1991. Natural enemies of European corn-borer *Ostrinia nubilalis* (Hubner) (Lepidoptera, Pyralidae) larvae in irrigated and drought-stressed corn. *J. Kansa Entomol. Soc.*, 64: 279–286

Grinnan, R., T.E. Jr. Carter and M.T.J. Johnson, 2013. The effects of drought and herbivory on plant–herbivore interactions across 16 soybean genotypes in a field experiment. *Ecol. Entomol.*, 38: 290–302

Hale, B.K., D.A. Herms, R.C. Hansen, T.P. Clausen and D. Arnold, 2005. Effects of drought stress and nutrient availability on dry matter allocation, phenolic glycosides, and rapid induced resistance of poplar to two lymantriid defoliators. *J. Chem. Ecol.*, 31: 2601–2620

Hasnain, M., M. Afzal, S. Nadeem and M.K. Nadeem, 2009. Morphological characters of different cotton cultivars in relation to resistance against Tetranychid mites. *Pak. J. Zool.*, 41: 241–244

Hermann, P., C.P.W. Zebitz and J. Kienzle, 1995. Wirkung verschiedener NeemAzal-Formulierungen auf larven der Florfliege *Chrysoperla carnea* Steph. *1*67 im Labor und Halbfreiland, *In 7th Int. Erfahrungsaust uber fur Schungserg*, pp: 114–118. Zum Okologischen Obstbau, LVWO Weinsberg

Holopainen, J.K. and J. Gershenzon, 2010. Multiple stress factors and the emission of plant VOCs. *Trends Plant Sci*., 15: 176–184

Huffman, F.R. and A.J. Mueller, 1983. Effects of beet armyworm (Lepidoptera: Noctuidae) infestation levels on soybean. *J. Econ. Entomol*., 76: 744–747

Inbar, M.I., H. Doostdar and R.T. Mayer, 2001. Suitability of stressed and vigorous plants to various insect herbivores. *Oikos*, 94: 228–235

IPCC (Intergovernmental Panel on Climate Change), 2001. *Climate Change: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change*. Houghton, J.T. and Ding Yihui (eds.). Cambridge University Press, Cambridge, UK

Isman, M.B., 2004. Factors limiting commercial success of neem insecticides in North America and Western Europe. *In*: *Neem: Today and in the New Millenium,* pp: 33–41. Koul, O. and S. Wahab (eds.). Kluwer Academic Press, Netherland

Johnson, M.T.J., 2011. Evolutionary ecology of plant defenses against herbivores. *Funct. Ecol.,* 25: 2–8

Kaboré, K.B., D. Dakouo and B. Thio, 2002. Efficiency and profitability of an IPM package against insects, blast, and nematodes in irrigated rice. *Pest Sci. Manage*., 27: 34–35

Karabhantanal, S.S., J.S. Awaknavar, R.K. Patil and B.V. Patil, 2005. Integrated Management of the Tomato Fruit borer, *Helicoverpa armigera* Hubner. *Karnataka J. Agric. Sci.,* 18: 977–981

Karuppaiah, V. and G.K. Sujayanad, 2012. Impact of Climate Change on Population Dynamics of Insect Pests. *World J. Agric. Sci*., 8: 240–246

Koul, O., J.S. Multani, S. Goomber, W.M. Daniewski and S. Berlozecki, 2004: Activity of some nonazadirachtin limonoids from *Azadirachta indica* against lepidopteran larvae. *Aust. J. Entomol.*, 43: 189–195

Kranthi, K.R., D. Russell, R. Wanjari, M. Kherde, S. Munje, N. Lavhe and N. Armes, 2002. In season changes in resistance to insecticides in *Helicoverpa armigera* (Lepidoptera: Noctuidae) in India. *J. Econ. Entomol.*, 95: 134–142

Long, S.P. and D.R. Ort, 2010. More than taking the heat: crops and global change. *Curr. Opinion Plant Biol.,* 13: 241–248

Lundgren, J.G., J.K. Fergen and W.E. Riedell, 2008. The influence of plant anatomy on oviposition and reproductive success of the omnivorous bug, *Orius insidiosus*. *Anim. Behav*., 75: 1495–1502

Manavalan, L.P., S.K. Guttikonda, L.S.P. Tran and H.T. Nguyen, 2009. Physiological and molecular approaches to improve drought resistance in soybean. *Plant Cell Physiol.* 50: 1260–1276

Mao, L., L.E. Jett, R.N. Story, A.M. Hammond, J.K. Peterson and D.R. Labonte, 2004. Influence of Drought Stress on Sweetpotato Resistance to Sweetpotato Weevil, Cylasformicarius (Coleoptera: Apoinidae), and Storage Root Chemistry. *Florida Entomol.*, 87: 261–267

Mattson, W.J. and R.A. Haack, 1991. The role of drought in outbreaks of plant-eating insects. *BioScience*, 37: 110–118

McMillin, J.D. and M.R. Wagner, 1995. Season and intensity of water stress: host-plant effects on larval survival and fecundity of *Neodiprion gillettei* (Hymenop-tera: Diprionidae). *Environ. Entomol.*, 24: 1251–1257

Miles, M. and R. Dutton, 2000. Spinosad—a naturally derived insect control agent with potential for use in integrated pest management systems in greenhouses. *In*: *Proc. British Crop Protec. Coun. Conf: Pests and Diseases* pp: 339–344. 13-16 Nov. Brighton, UK

Naqvi, N. and Nausheen, 2008. *Statistical supplement of economic survey, 2007-2008: Ch 2 Agriculture Ministry of Finance, Govt. of Pakistan*, pp: 1–25. Available on-line athttp://www.finance.gov.pk/admin/images/survey/chapters/Chapter 2 08-09.pdf accessed May 2009 (verified 27 May 2009)

Paritsis, J. and T.T. Veblen, 2011. Dendroecological analysis of defoliator outbreaks on *Nothofagus pumilio* and their relation to climate variability in the Patagonian Andes. *Global Change Biol.,* 17: 239–253

Patel, V.J., J.F. Dodia, A.M. Mehta and D.M. Korat, 2009. Evaluation of integrated module against paddy leaf folder, *Cnaphalocrocis medinalis* Guen. In middle Gujarat conditions. *Karnataka J. Agric. Sci.*, 22: 218–219

Praveen, P.M., 2000. Eco-friendly management of major pests of okra *Abelmoschus esculentus* (L.) Moench and tomato (*Lycopersicon esculentum* Mill). *Unpublished M.Sc. Thesis*, pp: 112–113. Tamil Nadu Agriculture University, Coimbatore, India

Price, P.W., 1991. The plant vigor hypothesis and herbivore attack. *Oikos,* 62: 244–251

Rasmann, S. and T.C.J. Turlings, 2007. Simultaneous feeding by above ground and below ground herbivores attenuates plant-mediated attraction of their respective natural enemies. *Ecol. Lett.,* 10: 926–936

Ravi, M., G. Santharam and N. Sathiah, 2008. Ecofriendly management of tomato fruit borer, *Helicoverpa armigera* (Hubner). *J. Biopest.,* 1: 134–137

Romo, C.M and J.M. Tylianakis, 2013. Elevated Temperature and Drought Interact to Reduce Parasitoid Effectiveness in Suppressing Hosts. *PLoS One*, 8: e58136

Rouf, F.M.A. and M.A. Sardar, 2011. Effect of crude seed extract of some indigenous plants for the control of legume pod borer *(maruca vitrata* f.) on country bean. *Bangl. J. Agric. Res.,* 36: 41–50

Rumpf, S., F. Hetzel and C. Frampton, 1997. Lacewings (Neuroptera: Hemerobiidae) and (Chrysopidae) and Integrated Pest Management: enzyme activity as biomarkers of sublethal insecticide exposure. *J. Econ. Entomol.*, 77: 1104–1105

Scholz, B., N. Parker and R. Lloyd, 2002. An evaluation of unsprayed INGARD cotton strips as nurseries for beneficial in dryland cotton on the Darling Downs. *In*: *Proc. 11th Aust. Cotton Conf. ACGRA,* pp: 297–306. Brisbane, Queensland, Australia

Showler, A.T., 2012. Drought and arthropod pests of crops. *In*: *Drought: New Research*, pp: 131–154. Neves, D.F and J.D. Sanz (eds.). Nova Science, 978-1-62100-769-2 Hauppauge, New York, USA

Showler, A.T. and P.J. Moran, 2003. Effects of drought stressed cotton, *Gossypiu hirsutum* L., on beet armyworm, *Spodoptera exigua* (Hubner), oviposition, and larval feeding preferences and growth. *J. Chem. Ecol*., 29: 1997–2011

Sinclair, T.R., 2011. Challenges in breeding for yield increase for drought. *Trends Plant Sci*., 16: 289–293

Soler, R., W.H. van der Putten, J.A. Harvey, LE Vet, M. Dicke, 2012. Root herbivore effects on aboveground multitrophic interactions: patterns, processes and mechanisms. *J. Chem. Ecol*., 38: 755–767

Tanweer, A. and L.N. Rao, 1997. Evaluation of certain integrated pest management components for management of whitefly and american bollworm of cotton. *Pestology*, 21: 47–52

Tanzubil, P.B., M. Zakariah and A. Alem, 2008. Integrating host plant resistance and chemical control in the management of Cowpea pests. *Aust. J. Crop Sci.,* 2: 115–120

Tariq, M., D.J. Wright, T.J.A. Bruce and J.T. Staley, 2013. Drought and Root Herbivory Interact to Alter the Response of Above-Ground Parasitoids to Aphid Infested Plants and Associated Plant Volatile Signals. *PLoS ONE*, 8: e69013. doi:10.1371/journal.pone.0069013

Trumble, J.T. and C.D. Butler, 2009. Climate change will exacerbate California's insect pest problems. *Calif. Agric.*, 63: 73–78

Vincent, D., C. Lapierre, B. Pollet, G. Cornic, L. Negroni, and M. Zivy, 2005. Water deficits affect caffeate O-methyltransferase, lignifications, and related enzymes in maize leaves. A proteomic investigation. *Plant Physiol.*, 137: 949–960

Vogt, H., U. Handel, E. Vinuela and H. Kleeberg, 1997. Field investigations on the efficacy of NeemAzal-T/S against *Dysaphis plantaginea* (Passerini) (Homoptera: Aphididae) and its effects on larvae of *Chrysoperla carnea* Stephens (Neuroptera: Chrysopidae). In: *Proc. 5th Workshop on Practice Oriented Results on Use and Production of Neem-ingredients and Pheromones*, pp: 105–114. C.P.W. Zebitz, Wetzlar, Germany

Walters, D., 2011. *Plant Defense: Warding Off Attack By Pathogens, Herbivores and Parasitic Plants*. Wiley-Blackwell, Oxford, UK

White, T.C.R., 1969. An index to measure weather-induced stress of trees associated with outbreaks of psyllids in Australia. *Ecology*, 50: 905–909

Williams, T., J. Valle and E. Viñuela, 2003. Is the naturally-derived insecticide Spinosad compatible with insect natural enemies? *Biocont. Sci. Technol.,* 13: 459–475

Yadav, S.S., J. Kumar, S.K. Yadav, S. Singh, V.S. Yadav, N.C. Turner and R. Redden, 2006. Evaluation of *Helicoverpa* and drought resistance in desi and kabuli chickpea. *PGR*, 4: 198–203

Yazdanpanah, Y., M. Tohidfar, M.E. Ashari, B. Ghareyazi, M.K. Jashni and M. Mosavi, 2009. Enhanced insect resistance to bollworm (*Helicoverpa armigera*) in cotton containing a synthetic *cry1 Ab* gene. *Ind. J. Biotechnol*., 8: 72–77

Zia, K., 2011. Sustainable management of whitefly, *Bemisia tabaci* (Genn.) (Homoptera: Aleyrodidae) in transgenic cotton. *Ph.D Thesis*, pp: 69–70. Department of Entomology, University of Agriculture, Faisalabad, Pakistan

(Received 22 March 2014; Accepted 15 July 2014)