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Performance of Transgenic Bt Cotton Against Insect Pest Infestation

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Abstract: Studies were carried out to investigate insect infestation on transgenic Bt and non-Bt cotton varieties and genotypes. The seeds of seven cotton varieties, viz., KMG-1, KMG-2, KMG-3, MS-1, MS-2 NIAB-78 and CRIS-134 were sown on May 15, 2002 in a completely randomized block design. The study comprised laboratory bioassay and field screening of different varieties and genotypes. Laboratory study indicated that transgenic Bt cotton was highly toxic to *Earias vittella* causing 100% larval mortality. While armyworm, *Spodoptera exigua* was tolerant, its mortality ranged between 13.3 to 53.3% on different varieties and genotypes. The results of field study revealed that the highest mean population (1.66 insect per leaf) of jassid was recorded on KMG-3 followed by 1.95 and 1.52 insects leaf on KMG-2 and KMG-1, respectively. Whitefly population ranged between 1.47 and 1.52 insects leaf on different varieties and genotypes. Whereas, thrips population remained fluctuating in different varieties and genotypes during the crop growth period. But genotypes like KMG-1, KMG-2 and KMG-3 which are crosses of Bt cotton and non-Bt cotton varieties were found harboring more thrips population. The larval population of spotted bollworm, *Earias* spp. indicated no infestation and live larvae were found on MS-1 and MS-2 varieties of Bt cotton. Maximum infestation of spotted bollworm was recorded on NIAB-78 (0.97 larva per plant) followed by other varieties and genotypes.

Key words: Transgenic Bt cotton, insect infestation, armyworm, bollworm

INTRODUCTION

Protection of crops from herbivorous insect pests by transferring insect resistance genes across the barriers to conventional plant breeding is one of the major goals of plant genetic engineering. Promising results have been achieved with transgenic plants expressing modified delta endotoxin genes from the soil bacterium *Baccillus thuringiensis*[1-3]. Cotton, *Gossypium hirsutum* L., plants have been modified genetically to incorporate recombinant DNA from the bacterium, *Bacillus thuringiensis* Berliner (B.t.) subsp. *Kurstaki* which codes for delta endotoxin proteins[4]. The crystalline proteins of B.t. Kurstaki are active against many lepidopteran larvae when ingested. The crystal proteins of B.t. Kurstaki are activated proteolytically in the larval midgut releasing toxic fragments that interact with the larval midgut epithelium, binding specifically to the brush border membrane vesicles[5]. In susceptible insects, gut paralysis and cessation of feeding occur within minutes after ingestion of the delta endotoxin protein[6]. Death of susceptible larvae occurs within 3-4 days depending upon insect species, larval age and dose[7].

Transgenic Bt cotton expressing Cry1A(b) and Cry1A(c) insecticidal proteins have shown significant protection against major cotton bollworm pests, *Helicoverpa zea* (Boddie), tobacco budworm, *Heliothis virescens*[8-10] *H. armigera*[11,12] and pink bollworm, *Pectinophora gossypiella*[13,14] in many countries of the world. Spotted bollworm, *Earias vittella* (F.) and *E. insulana* (Boisd.) are serious bollworms pests in Indo-Pakistan subcontinent and some north African countries. Information is lacking regarding the effectiveness of transgenic Bt cotton against *Earias* spp.

Cotton is the important cash crop of Pakistan. Pakistan is fourth largest producer of cotton in the world after China, USA and India. Bollworms are serious pests of cotton in Pakistan and inflict heavy damage to the crop which may vary from year to year but generally cause 30-40% yield reduction[15]. Bt cotton is cultivated since 1996 in the USA and many other countries like Australia, China, South Africa, India, Mexico and Argentina etc. Some progressive farmers in Pakistan have managed seeds of transgenic Bt cotton varieties and are cultivating since last 4-5 years. Present investigation was undertaken to study the insect pest infestation in Bt

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cotton varieties in comparison to the prevailing standard cotton varieties under laboratory and field conditions.

MATERIALS AND METHODS

The study was conducted on the Foundation Seed Multiplication Section, Agriculture Research Institute, Tandojam field in 2002. The seeds of 7 cotton varieties/genotypes were sown on May 5, 2002 in a completely randomized design with strip cropping. Each strip measuring 6.0x10.5 meters with 9 rows of each variety. For the purpose of taking observations, each strip was divided into four replications. All cotton plots were managed using recommended agronomic practices. No application of insecticides was made in experimental plots.

Plants: Seven cotton varieties and genotypes were used: (1) NIAB-78, this variety was developed in 1981 from the Delta pine 16xAC 134 and F1 was irradiated with gamma rays (30 Kr). The plant has 18-24 monopodia and 20-25 sympodia. (2) CRIS-134, this variety was developed by Cotton Research Institute, Sakrand. This variety is semi-dwarf with normal gossypol and good boll opening. (3) MS-1, this is a semi dwarf variety with 95 cm plant height, four monopodia and 14 sympodia. (4) MS-2, this is also a semi dwarf variety with 1-3 monopodia and 18 sympodia and 76 cm plant height. These (MS-1 and MS-2) are transgenic varieties expressing insecticidal delta endotoxin from the bacterium, *B. thuringiensis* subspecies *Kurstaki*. (5) KMG1 was created by crosses involving MS-1 and Niab-78, (6) KMG2, this genotype is a product of crosses between NIAB-78 and MS-2. (7) KMG3, this genotype is a result of crosses between MS-1 and CIM-109. All these genotypes were developed through the conventional plant breeding procedures. F2 progeny of above genotypes was tested in present studies. Plants were grown in the field to produce flower buds used in this study.

Insects: Spotted bollworm, *Earias vittella* larvae were collected from okra fields. The larvae were reared on okra fruit under laboratory conditions till pupation. After adult emergence, male and female adults were introduced into egg-laying chambers, provided with 10% W/V sucrose solution as adult food and kept for egg laying. Egg masses of armyworm, *Spodoptera exigua* were collected from cotton field for this study.

Experimental procedure: A uniform cohort of neonates, collected at the same time, of each species were used for this study. Flower buds to feed the larvae were collected each day from the field grown Bt and non-Bt cotton plants. Flower buds were placed in glass petridishes (15 cm dia.) and neonate larvae of both species were introduced onto buds. Five larvae were placed in every petridish. Flower buds were replaced daily till pupation. The experiment was replicated three times. Each replication consisted of 15 larvae of *S. exigua* and 15 larvae of *E. vittella*. After adult emergence, percent survival to adult stage was calculated.

Insects and delta collection: During the study natural infestation of following insects occurred: whitefly, *Bemisia tbaaci;* thrips, *Thrips tabaci;* jassid, *Amrasca devastans* and spotted bollworm, *Earias* spp. Observations on infestation of cotton by sucking insect pests and spotted bollworm were started 57 days after sowing and continued till harvest. For recording observations, five plants were selected at random from each replication per treatment. From each plant, data were recorded from five leaves, two leaves each from bottom and middle portions and one leaf from the top portion of a plant. Data collected for bollworm were number of larvae in terminals, flower buds and bolls. Data were collected at weekly intervals.

Statistical analysis: All data collected were analysed by analysis of variance (ANOVA) and means were separated using least significant difference (LSD) method[16].

RESULTS AND DISCUSSION

There was no survival of spotted bollworm larvae to pupal stage fed on Bt cotton varieties and genotypes (Table 1). The survival of armyworm varied significantly (20.01; df=6.12; P<0.01) on different varieties and genotypes of cotton (Table 1). Survival of armyworm larvae to adult stage was the minimum for those larvae which were fed on Bt cotton MS-2 variety.

Table 1: Percentage of larvae surviving to adult sgtage for spotted bollworm and armyworm fed Bt and non-Bt cotton flower buds in a no-choice study

Flower bud genotype	Spotted bollworm larval survival to adult stage		Armyworm larval survival to adult stage	
	$\bar{x}$	%	$\bar{x}$	%
KMG1	0.00	0.00	12.67de	84.4
KMG2	0.00	0.00	13.00e	86.7
KMG3	0.00	0.00	11.00bc	73.3
MS1	0.00	0.00	11.67cd	77.8
MS2	0.00	0.00	7.00a	46.7
CRIS-134	-	-	10.33b	68.9
NIAB-78	-	-	10.67bc	71.1

Means followed by same letter are not significantly different from each other by LSD method, cd 0.05=1.02

Table 2: Average per leaf population of jassid, *Amrasca devastans* on different varieties and genotypes of cotton crop ($\bar{x}$± SD insects)[1]

Date	KMG-1	KMG-2	KMG-3	Ms-1	Ms-2	Niab-78	CRIS-134	Average
11.07.2002	1.16±0.22	1.06±0.14	1.52±0.18	0.71±0.00	0.71±0.00	0.71±0.00	1.26±0.05	1.02±0.32I
18.07.2002	1.48±0.34	0.94±0.08	0.71±0.00	0.71±0.00	0.71±0.00	1.32±0.07	1.15±0.22	1.003±0.32j
25.07.2002	0.71±0.00	1.26±0.26	1.14±0.22	0.86±0.05	0.94±0.12	1.27±0.16	0.96±0.18	1.02±0.21I
31.07.2002	0.79±0.16	1.88±0.19	1.38±0.19	1.09±0.25	0.84±0.00	1.56±0.13	1.11±0.19	1.23±0.39gh
07.08.2002	2.23±0.25	2.69±0.05	3.14±0.05	0.97±0.12	0.80±0.06	1.51±0.15	0.89±0.11	1.74±0.94bc
14.08.2002	2.52±0.33	2.75±0.09	3.01±0.15	1.34±0.43	1.42±0.38	1.48±0.12	1.04±0.18	1.93±0.73a
21.08.2002	1.07±0.26	1.12±0.12	1.48±0.37	0.89±0.06	1.29±0.19	2.08±0.11	0.92±0.10	1.26±0.42gh
28.08.2002	1.15±0.15	1.29±0.14	1.36±0.04	1.25±0.15	1.25±0.14	1.35±0.16	1.40±0.07	1.29±0.08g
04.09.2002	0.94±0.08	1.16±0.11	1.17±0.14	1.57±0.16	1.29±0.10	1.62±0.09	1.17±0.21	1.27±0.24gh
11.09.2002	1.39±0.13	1.14±0.12	1.15±0.10	1.17±0.10	1.11±0.13	1.25±0.20	1.06±0.14	1.18±0.11h
18.09.2002	1.07±0.18	1.49±0.16	1.24±0.10	1.21±0.19	1.17±0.15	1.07±0.04	1.20±0.10	1.20±0.14gh
25.09.2002	1.29±0.17	1.16±0.04	1.97±0.05	1.41±0.34	1.73±0.44	1.26±0.10	1.31±0.23	1.44±0.29f
02.10.2002	1.69±0.15	1.35±0.15	1.79±0.03	1.45±0.22	1.58±0.15	1.35±0.17	1.68±0.03	1.55±0.17e
09.10.2002	2.05±0.12	2.04±0.23	2.07±0.12	1.69±0.34	1.58±0.22	1.36±0.39	1.56±0.28	1.76±0.28b
16.10.2002	2.21±0.14	2.01±0.18	1.35±0.19	1.67±0.26	1.16±0.14	1.77±0.17	1.01±0.22	1.65±0.39cd
23.10.2002	1.95±0.15	1.87±0.18	1.83±0.14	1.60±0.32	1.69±0.17	1.21±0.12	1.27±0.24	1.63±0.29de
30.10.2020	1.84±0.18	1.68±0.36	1.95±0.11	1.61±0.25	1.81±0.24	1.24±0.16	1.26±0.05	1.62±0.28de
06.10.2002	1.89±0.26	1.76±0.26	1.63±0.34	1.66±0.23	1.33±0.14	1.28±0.13	1.64±0.26	1.59±0.22de
Mean±SD	1.52±0.54c	1.59±0.17b	1.66±0.14a	1.27±0.337e	1.27±0.15e	1.37±0.13d	1.21±0.23e	- - - -

1. Square root $\sqrt{x+0.5}$ transformed data, Means followed by the same letter are not significantly (P< 0.05) different from each other by LSD method
cd 0.05 for varieties = 0.06, dates = 0.09

Table 3: Average per leaf population of white Fly, *Bemisia tabaci* on different varieties and genotype of cotton crop ($\bar{x}$±SD insects)[1]

Date	KMG-1	KMG-2	KMG-3	Ms-1	Ms-2	Niab-78	CRIS-134	Average
11.07.2002	1.14±0.28	1.05±0.07	1.19±0.31	0.83±0.14	0.71±0.00	0.80±0.12	0.71±0.00	0.91±0.21j
18.07.2002	1.6±0.21	1.83±0.14	1.82±0.10	0.71±0.00	0.87±0.06	1.18±0.25	0.81±0.06	1.26±0.48h
25.07.2002	1.8±0.12	1.89±0.08	1.84±0.09	1.±0.06	0.95±0.08	1.16±0.24	0.99±0.13	1.37±0.44fg
31.07.2002	0.87±0.05	0.96±0.18	0.81±0.12	1.18±0.11	0.80±0.12	1.18±0.11	0.97±0.10	0.96±0.16j
07.08.2002	0.89±0.06	1.09±0.08	1.02±0.13	1.17±0.91	1.28±0.16	1.42±0.04	1.04±0.17	1.11±0.17i
14.08.2002	1.08±0.15	1.02±0.14	1.15±0.23	0.97±0.12	1.53±0.08	2.28±0.17	1.12±0.16	1.31±0.46gh
21.08.2002	1.58±0.24	1.06±0.16	1.55±0.22	1.07±0.14	1.17±0.20	2.07±0.14	1.20±0.27	1.38±0.37fg
28.08.2002	1.39±0.12	1.37±0.12	1.43±0.09	1.14±0.26	1.08±0.17	1.37±0.25	1.34±0.13	1.31±0.13gh
04.09.2002	1.26±0.25	1.06±0.16	1.21±0.22	0.83±0.14	0.86±0.14	1.25±0.18	0.97±0.12	1.06±0.18i
11.09.2002	1.05±0.25	1.24±0.17	1.11±0.13	1.04±0.13	1.17±0.11	1.30±0.11	1.12±0.04	1.14±0.09i
18.09.2002	1.54±0.14	1.53±0.11	1.46±0.08	1.02±0.09	1.24±0.18	1.40±0.14	1.19±0.19	1.34±0.19gh
25.09.2002	1.64±0.08	1.78±0.09	2.22±0.10	1.25±0.21	1.61±0.08	1.31±0.11	1.39±0.28	1.60±0.34cd
02.10.2002	1.73±0.07	1.43±0.07	1.58±0.05	1.31±0.16	1.64±0.23	1.40±0.07	1.56±0.14	1.52±0.15de
09.10.2002	1.94±0.15	2.32±0.24	1.92±0.11	1.42±0.16	1.57±0.19	1.49±0.19	1.56±0.14	1.75±0.32b
16.10.2002	2.05±0.03	2.06±0.07	1.98±0.14	1.41±0.28	1.92±0.07	1.95±0.05	1.74±0.18	1.87±0.23a
23.10.2002	2.01±0.07	1.77±0.12	1.68±0.03	1.59±0.28	1.75±0.22	1.16±0.25	1.36±0.07	1.612±0.28c
30.10.2020	1.87±0.11	1.9±0.18	1.76±0.37	1.45±0.27	1.50±0.38	1.40±0.07	1.36±0.12	1.60±0.23cd
06.10.2002	1.99±0.08	1.64±0.17	1.51±0.14	1.26±0.19	1.23±0.19	1.34±0.24	1.20±0.18	1.45±0.28ef
Mean±SD	1.52±0.13a	1.50±0.13a	1.51±0.14a	1.14±0.23e	1.27±0.14c	1.41±0.35b	1.20±0.14d	- - - -

1. Square root $\sqrt{x+0.5}$ transformed data, Means followed by the same letter are not significantly (P< 0.05) different from each other by LSD method
cd 0.05 for varieties = 0.05, dates = 0.08

Jassid, *Amrasca devastans* Dist.: Jassid, *A. devastans* was found infesting KMG-1, KMG-2, KMG-3 and CRIS-134 cotton genotypes and varieties on the first observation in the second week of July. Where as no pest infestation was found on MS-1, MS-2 and Niab-78 varieties. All cotton varieties and genotypes remained infested with *A. devastans* throughout the remaining period of crop growth (Table 2). In almost all varieties and genotypes pest population increased slowly and reached the peak in the second fortnight of August. *A. devastans* population started to decline subsequently on almost all varieties and genotypes. There was a significant (F=64.02; df=17.37; p<0.01) variation in population growth of *A. devastans* on different varieties and genotypes during the period of growth. On overall seasonal mean basis pest infestation on different varieties and genotypes differed significantly (F=63.44; df=6.37; P<0.0001). The highest (1.66 *A. devastans* per leaf) population was found on KMG-3 followed by 1.59 and 1.52 on KMG-2 and KMG-1, respectively. Where as the minimum population of 1.21 insects per leaf was recorded on CRIS-134.

White fly, *Bemisia tabaci* Genn.: Whitefly, *B. tabaci* was found infesting KMG-1, KMG-2, KMG-3, MS-1 and Niab-78 cotton genotypes and varieties in the second week of July. There was no infestation of *B. tabaci* on MS-2 and CRIS-134 on July 11, 2002. *B. tabaci* infestation started to increase in all genotypes and varieties of cotton in the subsequent observations. The highest *B. tabaci* population of 2.05, 2.32, 2.22, 1.56, 1.92, 2.28 and 1.74 per leaf was found in KMG-1, KMG-2, KMG-3, MS-1, MS-2, Niab-78 and CRIS-134, respectively on different dates

Table 4: Average per leaf population of thrips, *Thrip tabaci* on different varieties and genotypes of cotton crop. ($\bar{x}$±SD larvae)[1]

Date	KMG-1	KMG-2	KMG-3	Ms-1	Ms-2	Niab-78	CRIS-134	Average
11.07.2002	1.52±0.05	1.74±0.06	1.20±0.17	0.71±0.00	0.86±0.11	3.23±0.05	0.71±0.00	1.42±0.89ij
18.07.2002	1.79±0.34	1.89±0.09	1.58±0.07	1.43±0.38	1.46±0.15	1.96±0.24	1.49±0.18	1.65±0.22g
25.07.2002	2.17±0.24	2.28±0.07	2.08±0.10	2.04±0.16	2.03±0.20	2.04±0.22	1.91±0.34	2.07±0.12e
31.07.2002	2.36±0.13	3.02±0.16	3.47±0.36	1.58±0.18	1.47±0.20	1.96±0.09	1.80±0.05	2.23±0.76d
07.08.2002	3.49±0.19	3.41±0.15	3.92±0.15	2.38±0.22	2.11±0.08	2.29±0.10	2.80±0.32	2.92±0.69a
14.08.2002	3.42±0.00	2.84±0.12	3.11±0.25	2.30±0.33	2.70±0.17	1.17±0.17	2.72±0.15	2.61±0.73b
21.08.2002	2.69±0.88	2.55±0.11	1.77±0.38	2.1±0.34	3.12±0.18	1.44±0.23	3.18±0.24	2.40±0.66c
28.08.2002	0.83±0.09	1.06±0.14	1.29±0.55	2.04±0.06	2.16±0.24	0.80±0.17	3.22±0.05	1.63±0.89gh
04.09.2002	0.97±0.24	0.95±0.08	1.88±0.11	0.89±0.15	0.74±0.06	1.87±0.08	2.08±0.08	1.34±0.57jk
11.09.2002	1.15±0.32	0.77±0.12	0.99±0.18	0.71±0.00	0.80±0.12	1.12±0.08	1.10±0.20	0.94±0.18lm
18.09.2002	0.95±0.00	0.97±0.13	1.09±0.29	0.91±0.18	0.92±0.14	1.11±0.12	1.20±0.37	1.02±0.11L
25.09.2002	0.80±0.12	0.83±0.14	1.03±0.17	0.71±0.00	0.74±0.06	1.19±0.21	0.86±0.17	0.88±0.17m
02.10.2002	1.74±0.32	1.72±0.23	1.46±0.18	0.98±0.21	0.86±0.11	1.25±0.18	1.09±0.12	1.3±0.35k
09.10.2002	2.02±0.12	2.22±0.14	2.29±0.18	1.11±0.11	1.16±0.29	1.38±0.44	1.17±0.19	1.62±0.53gh
16.10.2002	2.12±0.15	2.35±0.17	2.33±0.14	1.34±0.33	1.65±0.30	1.70±0.11	1.22±0.12	1.81±0.46f
23.10.2002	2.08±0.03	1.74±0.13	1.73±0.19	1.41±0.40	1.32±0.29	1.09±0.12	1.32±0.12	1.52±0.59hi
30.10.2020	2.35±0.21	2.49±0.19	2.41±0.13	1.90±0.17	1.54±0.23	1.64±0.36	2.44±0.23	2.10±0.41e
06.10.2002	2.43±0.13	2.32±0.16	2.35±0.13	2.06±0.29	1.96±0.40	1.35±0.32	1.74±0.17	2.02±0.38e
Mean±SD	1.93±0.19a	1.95±0.13a	1.99±0.20a	1.47±0.18d	1.53±0.18cd	1.58±0.18c	1.78±0.17b	- -

1. Square root √ x + 0.5 transformed data, Means followed by the same letter are not significantly (P< 0.05) different from each other by LSD method cd 0.05 for varieties = 0.0689, dates = 0.1105

Table 5: Average per plant population of spotted bollworm, *Earias* spp; on different varieties and genotype of cotton crop ($\bar{x}$±SD larvae)[1]

Date	KMG-1	KMG-2	KMG-3	Ms-1	Ms-2	Niab-78	CRIS-134	Average
11.07.2002	0.71±0.00	0.74±0.06	0.71±0.00	0.71±0.00	0.71±0.00	0.89±0.06	0.71±0.00	0.74±0.06ij
18.07.2002	0.71±0.00	0.71±0.00	0.77±0.00	0.71±0 .00	0.71±0.00	0.95±0.08	0.71±0.00	0.74±0.09ij
25.07.2002	0.71±0.00	0.74±0.06	0.77±0.07	0.71±0.00	0.71±0.00	0.96±0.10	0.71±0.00	0.75±0.13hij
31.07.2002	0.71±0.00	0.77±0.07	0.83±0.09	0.71±0.00	0.71±0.00	1.07±0.09	0.71±0.00	0.78±0.13fghi
07.08.2002	0.71±0.00	0.74±0.06	0.71±0.00	0.71±0.00	0.71±0.00	0.99±0.09	0.71±0.00	0.75±0.11hij
14.08.2002	0.71±0.00	0.71±0.00	0.71±0.00	0.71±0.00	0.71±0.00	0.71±0.00	0.80±0.12	0.72±0.04j
21.08.2002	0.71±0.00	0.95±0.06	0.74±0.06	0.71±0.00	0.71±0.00	0.91±0.08	0.74±0.06	0.78±0.09ghij
28.08.2002	0.89±0.06	0.89±0.12	0.97±0.10	0.71±0.00	0.71±0.00	0.87±0.06	0.92±0.06	0.85±0.10def
04.09.2002	0.92±0.10	0.97±0.15	0.88±0.14	0.71±0.00	0.71±0.00	0.92±0.06	0.97±0.12	0.87±0.12cde
11.09.2002	0.97±0.13	0.89±0.10	0.93±0.19	0.71±0.00	0.71±0.00	1.05±0.08	0.95±0.08	0.88±0.13cd
18.09.2002	0.95±0.08	0.87±0.05	0.90±0.06	0.71±0.00	0.71±0.00	0.91±0.17	0.89±0.15	0.84±0.09defg
25.09.2002	0.81±0.12	0.86±0.14	0.81±0.06	0.71±0.00	0.71±0.00	0.91±0.18	0.92±0.06	0.81±0.08efgh
02.10.2002	0.84±0.15	0.74±0.08	0.84±0.10	0.71±0.00	0.71±0.00	0.90±0.10	0.84±0.18	0.79±0.11efg
09.10.2002	0.97±0.10	1.02±0.10	1.07±0.05	0.71±0.00	0.71±0.00	0.97±0.10	0.97±0.08	0.92±0.13abc
16.10.2002	1.14±0.12	1.04±0.12	1.05±0.23	0.71±0.00	0.71±0.00	1.11±0.11	1.11±0.13	0.99±0.18a
23.10.2002	1.08±0.18	1.02±0.05	1.02±0.12	0.71±0.00	0.71±0.00	1.14±0.09	1.05±0.08	0.96±0.17ab
30.10.2020	1.01±0.21	1.05±0.05	1.05±0.07	0.71±0.00	0.71±0.00	1.19±0.19	1.05±0.08	0.97±0.18a
06.10.2002	1.02±0.09	0.97±0.15	0.97±0.12	0.71±0.00	0.71±0.00	0.97±0.10	0.97±0.10	0.91±0.13bcd
Mean±SD	0.86±0.07b (0.25)	0.87±0.12b (0.27)	0.87±0.08b (0.26)	0.71±0.00c (0.00)	0.71±0.00c (0.00)	0.97±0.10a (0.44)	0.87±0.06b (0.26)	_ _

1. Square root √ x + 0.5 transformed data, Means followed by the same letter are not significantly (P< 0.05) different from each other by LSD method (original data in brackets), cd 0.05 for varieties = 0.0413, dates = 0.066

during crop growth (Table 3). The analysis of data showed that there was a significant (F=66.31;df=6.37; P<0.001) difference in seasonal population means of *B. tabaci* developing on different genotypes and varieties of cotton. Similarly, the population development of *B. tabaci* on different dates during crop growth on different genotypes and varieties was also significantly (F=71.75; df=17.37; P<0.001) different from each other.

Thrips, *Thrips tabaci* Lind.: The results of population development of *T. tabaci* on different genotypes and varieties of cotton are shown in Table 4 which indicate that except MS-1 and CRIS-134 pest infestation was prevalent in all the remaining genotypes and varieties of cotton on July 11, 2002. *T. tabaci* infestation was recorded on all the genotypes and varieties in the subsequent observations after one week, pest population remained fluctuating in different varieties and genotypes throughout the growth period of crop. Analysis of variance of data showed that there was a significant (F=77.11; df=6.37; P<0.001) difference in population growth of *T. tabaci* on different genotypes and varieties of cotton. Genotypes like KMG-1, KMG-2 and KMG-3 which are crosses of BT cotton and local non-Bt cotton varieties were harboring the significantly more population of thrips compared with CRIS-134 and Niab-78. Whereas, MS-1, Bt cotton variety was the most resistant variety harboring the least population of thrips compared with the remaining genotypes and varieties. Thrips population developing on different dates of crop growth was also significantly ($F=208.40$; $df=13.75$; $P<0.001$) different from each other.

Spotted bollworm, *Earias* spp.: Table 5 shows the larval population of *Earias* spp. infesting different genotypes and varieties during present study. No infestation (Zero infestation) and live larvae were found on MS-1 and MS-2 varieties of Bt cotton. Whereas maximum infestation of the pest was recorded on Niab-78. The three genotypes which have been developed through crosses with Bt cotton were at par with CRIS-134 in terms of infestation of *Earias* spp. and were not statistically different ($F=42.16$; $df=6.37$; $P<0.001$) from each other. Population of *Earias* spp. developing on different dates was significantly ($F=13.13$; $df=17.37$; $P<0.001$) different.

Some lepidopterous larvae are intrinsically more tolerant of transgenic Bt cotton than others. Ashfaq *et al.*[17] found low level of mortality in beet armyworm, *Spodoptera exigua* fed Bt cotton. Henneberry *et al.*[18] reported tobacco budawrom, *Heliothis virescens* (F). larvae were highly susceptible to feeding on bt cotton leaves or flower buds with 100 and 96% mortality occurring with in four days, respectively, compare to an average mortality of 95% for cabbage looper, *Trichoplusia ni* (Hub) and 57% for beet armyworm, *Spodoptera exigua* (Hub) after 8 days on Bt cotton leaves. Adamezyk *et al.*[19] also reported differences in larval survival and development of bollworm, *Heliocoverpa zea* and fall armyworm, *Spodoptera frugiperla* (J.E: Smith) fed Bt cotton varieties. Present study also indicated variation in susceptibility of spotted bollworm and armyworm larvae to transgenic Bt cotton. Spotted bollworm was highly susceptible to Bt cotton with 100% mortality when larvae were fed on Bt cotton flower buds. Armyworm larvae were more tolerant to Bt cotton and mortality ranged between 13.3 to 53.3% on different varieties and genoptypes of cotton. Increased tolerance of *Spodoptera* spp. to transgenic Bt cotton has also been reported from other studies[20-22].

The sucking insect pests of cotton comprise Jassid, *Amrasca devastans;* whitefly, *Bemisica tabaci* and Thrips, *Thrips tabaci.* These insects are important during seedling and vegetative stage because they suck the sap of the plant, making it weak and in case of severe infestation wilting and shedding of leaves. In the advanced stage of plant, Hendrix[23] found co-relation between *B. tabaci* population and amount of honeydew sugar received by fibre of open bolls and stickiness of resulting cotton lint. Taley *et al.*[24] reported 16.8% loss of yield of cotton due to sucking pests (Hemiptera). Singh and Lakra[25] estimated an average reduction in yield of cotton due to infestation of *A. devastans*, which was 15.9%. Whereas, Baloch *et al.*[26] observed that the thrip population of 9-13 per leaf and jassid 1 per leaf up to September did not significantly affect cotton yield.

In present study significantly higher population of jassid *A. devastans* was recorded in genotypes like KMG-1, KMG-2 and KMG-3 compared with remaining varieties under study including conventional varieties Niab-78 and CRIS-134 (Table 2). Significantly higher population of *B. tabaci* are observed in genotypes KMG-1, KMG-2 and KMG-3, followed by Niab-78, MS-2 and CRIS-134. Whereas minimum population of 1.147 *B. tabaci* per leaf was found in MS-2 Bt cotton variety. Similarly, significantly higher *T. tabaci* population was recorded in genotype which were developed by crossing Bt cotton and conventional cotton varieties. Minimum pest population was recorded (1.47 per leaf) on Bt cotton variety MS-2.

Ning *et al.*[27] conducted study on major insect pests on Bt transgenic and conventional cotton and found aphid population slightly higher in Bt cotton. Bai *et al.*[28] also reported high *Aphis gossypii* population in Bt cotton than conventional cotton. Sun *et al.*[29] investigated the effect of Bt cotton on population of major insect pests and found that *Aphis gossypii*, *Thrips tabaci* and *Lygus lucorum* population increased in Bt cotton fields as compared with normal cotton fields. Similarly, Deng *et al.*[22] found no resistance in Bt cotton against whitefly, *B. tabaci.*

Cotton is a delicate crop, attacked by a large number of insect pests. Amongst different insect pests, which attack cotton, bollworms are very destructive. Boll worms, *Helicoverpa (Heliothis)* spp and *Pectinophora gossypiella* are distributed through out the world where ever cotton is grown, whereas, *Earias* spp. a serious pest of cotton in Indo-Pakistan subcontinent and some Middle Eastern countries like Egypt. These bollworm species cause shedding of fruiting bodies of cotton and reduce the potential yield of cotton crop. There are many studies, which report the yield loss in cotton due to bollworms. Taley *et al.*[24] reported 71.44% yield loss due to bollworms, while Singh and Lakra[25] observed that on an average 36.2% reduction in yield was due to bollworms. Butter *et al.*[30] proposed an action threshold of 2-3 larvae of bollworms, *P. gossypiella, Earias* spp and *H. armigera* per plant was effective for initiation of insecticide control. Bt cotton contains a gene to express *Bacillus thrugiensis* subspecies kurstaki. Bt kurstaki is specifically effective against lepidopterous larvae. Therefore, Bt cotton is mostly effective against bollworms of cotton.

In the present study maximum infestation of *Earias* spp. was found in Naib-78 followed by KMG-2, KMG-3, CRIS-134 and KMG-1. Whereas, no (zero) infestation of *Earias* spp. was found on MS-1 and MS-2, which are Bt cotton varieties. Many workers have reported similar results on the infestation of bollworms in Bt cotton; for example, Ning *et al.*[27] conducted study on major insects on Bt cotton and conventional cotton and found significantly different survival of *H. armigera* on Bt and conventional cotton. Chen *et al.*[31] studied the resistance of Bt transgenic cotton to *H. armigera* and found obvious changes in resistance during cotton stage was strong which decreased at square stage and coincided with changes in the content of insecticidal protein in leaves. Positive co-relation between Bt toxin level and total protein and water soluble protein were found and it was indicated that Bt toxin level might be associated with the protein metabolism of Bt cotton. Similarly, Liu *et al.*[32] also found the highest resistance of Bt cotton to *H. armigera* at the last ten days of May and July which were 94.5 and 83.3% but resistance was lowest in August (22.7%). Further, they found that different Bt cotton plant parts had different resistance levels against larvae of *H. armigera.*

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