Pakistan J. Zool., pp 1-10, 2021. DOI: https://dx.doi.org/10.17582/journal.pjz/20190506110521

Response of Mid and Short Season Promising Genotypes of Cotton Crop to *Earias vittella* (Fab.) Infestation in Punjab, Pakistan

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Article Information
Received 06 May 2019
Revised 30 June 2020
Accepted 13 February 2021
Available online 04 August 2021

Authors' Contribution
MTJ and MAS conceived and designed the experiments. MTJ and MB analyzed the data, prepared the figures and tables, and wrote the manuscript. SAS and MAS reviewed the manuscript and read and approved the final manuscript.

Key words
***E. vittella*, Mid-season cotton variety, Short season cotton variety, Critical period, Loss compensation.**

ABSTRACT

Spotted bollworm, *Earias vittella* Fab (Lepidoptera: Noctuidae) is serious Asiatic pest, particularly associated with cotton in Pakistan. The study was planned to determine response of long and short duration cotton genotypes to *E. vittella* infestation. Field experiment was conducted at the Central Cotton Research Institute, Multan for two years. Long and short duration genotypes were sown during the 3rd week of May to investigate their response to *E. vittella. E. vittella* infestation (damage in fruits and larval population) was almost similar during both the years of experimentation. However, the fruiting parts were higher during second year as compared to the first year. The response of the genotypes CIM-496 and CIM-506 was variable to *E. vittella* infestation in fruiting parts and damage in mature bolls. Treatments showed significant impact on fruiting parts, number of damage fruits and larval population. However, no significant interaction was observed between the varieties and treatments. The most critical months were August and September in which the rate of IMF damaged by single larva was 4.5 and 4.1 and MB at the rate of 1.5 and 1.6 in CIM-496 while 3.6 and 4.1 IMF and 1.7 MB damage per larva in CIM-506, respectively. By controlling the pest infestation up to70-80% damage or 66% larval population, the yield was increased by 22-24% in long or short duration genotypes. Inevitable losses due to *E. vittella* were 0.8% in IMF or 0.3-0.4% in MB even with 10 applications in both the genotypes. The critical tolerance period for the long duration genotype CIM 496 was the last week of August and for short duration genotype CIM-506 was the second week of August. Similarly losses compensation was 4.5 and 9.1% higher in long duration genotypes as compared to short duration genotype in 1%TL and TL2, respectively. It was concluded that *E. vittella* can cause 22-24% fruiting losses if the pest is not controlled. Plant protection measures should therefore be taken before the critical tolerance period.

INTRODUCTION

Earias vittella is a serious Asiatic pest of Malvaceae and particularly associated with cotton (Abro *et al*., 2003). The larvae of *E. vittella* feed on growing vegetative parts, developing seed in the cotton bolls, shoots of the main stem, tops of side branches and flower buds (Kumar and Urs, 1988; Abhilash and Patil, 2008). This pest causes upto 14, 51, 3 and 69 % damage to seedlings, buds, flowers and bolls (Arif and Attique, 1990; Kamaluddin, 1994; Dhillon and Sharma, 2004) and as a result of high infestation, 20% seed cotton yield is lost (Khan, 2011). It remains active throughout the year, produces 6-8 generations and reduces the seed cotton yield from 66 to 91%, when this pest infests the bolls during August to September (Sidhu and Sandhu, 1977). *E. vittella* showed significant effects on cotton species *Gossypium hirsutum* L. for larval survival, pupation, adult emergence, egg hatchability and growth index over *G. arboreum* (Dhillon and Sharma, 2004). In Pakistan, most of the commercial non Bt-cotton varieties belong to *G. hirsutum* and were found susceptible to *E. vittella* (Abro *et al*., 2003; Razaq *et al*., 2004). In any cropping system, genotypes with varied crop maturity duration play vital role in development of crop management strategies (Raper and Gwathmey, 2014). For instance cultivation of short season varieties of cotton instead of conventional full season varieties offer several potential benefits to cotton growers (Silvertooth and Farr, 2001). One benefit of earliness in cotton was thought to reduce late season pest infestations and diseases and increase at economic return by reducing input cost (Anderson *et al*., 1976). In

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0030-9923/2021/0001-0001 $ 9.00/0

Pakistan, infestation by the late season cotton pests; *i.e. Pectinophora gossypiella* (Saunders) and *Bemisia tabaci* (Gennadius), during September and first week of October and high population of *Helicoverpa armigera* (Hübner) in 3rd week of September to 4th week of October cause severe problems to cotton (Baloch *et al*., 2014). In case of these serious insect pests, entomologists stress the importance of utilizing a short season cotton production pattern on a wide-spread basis to extend the host-free period (Silvertooth and Farr, 2001). On other hand, the short season cotton varieties offer no compensation time for early season square loss in case of early infestation of *E. vittella,* which needs more protection of these squares than those formed late in the season (Ahmad and Malik, 1996). Therefore the exact combination of conditions leading to a definite advantage of short season variety over mid or full season is not clear (Silvertooth and Farr, 2001).

Considering the importance the integrated pest management (IPM) in the cotton cropping system, the present study was planned to evaluate two commercial and promising non-Bt genotypes having distinct growth periods (long and short duration) to determine response of these genotypes to *E. vittella* infestation under sprayed and unsprayed conditions. This study in future, will lead to determine the critical period of tolerance to *E. vittella* infestation and to develop management strategies for the control of this pest for each genotype.

MATERIALS AND METHODS

Experimental design

Field experiments were conducted at the Central Cotton Research Institute (30°12'N, 71°26'E) Multan, Pakistan over two crop seasons. Two commercial genotypes, CIM-496 and CIM-506, were sown during the 3rd week of May, in a split plot design. The genotypes were the main plots with two conditions, (1%TL = Sprayed at approximately 1% damage level and TL2 =Unsprayed) as sub plots and three replications. Plot size, row to row and plant to plant distance was 6.9 x 12.2 m, 0.76m and 22.9 cm, respectively. All other agronomic requisites were provided when required.

Sampling of E. vittella *infestation*

Fruiting parts (healthy and damaged) along with larval population in both immature fruits and mature bolls and total fruits were recorded. For analysis, various abbreviations were used as: IMF (immature fruits), MB (mature bolls), TFP (total fruiting parts), IMF-dm, MB-da, TFP-da (damage in the respective fruiting parts) and IMF-lar, MB-lar, TFP-lar (larval population in the respective fruiting parts). For regular weekly pest scouting, five randomly selected plants in a row were examined for healthy and freshly damaged fruits with larval population. However, to ascertain the insecticidal impact on *E. vittella* infestation data was recorded after three days of each insecticide application. Observation was initiated from 1st July till mid October and last week of October in the respective years of the study. Before the crop was harvested in the 3rd week of October in 1st crop season and 3rd week of November in 2nd crop season, unopened bolls (UOB), open bolls (OB) and total bolls (TB) were also recorded, to determine recovery of losses due to *E. vittella* infestation**.**

General characteristics of CIM-496 and CIM-506

Khan *et al*. (2011) classified CIM-496 as mid-season genotype and CIM-506 as short season genotype on the basis of crop duration. The former genotype completes its cycle till November (140-160 days) whereas the later one terminates within 100-120 days (upto mid October).

Insecticides and spray applications

Three commercial insecticides were used in rotation including spinosad (Tracer) 480 EC (Dow Agro Sciences) @197.6 ml hec^{-1}, deltamethrin (Decis) 10EC (Bayer) @ 815.1 ml hec^{-1} and cypermethrin (Arrivo) 10EC (Bayer) @ 815.1 ml hec^{-1}. Spray application was made at or before availing 1% immature fruit damage using simple mathematical equation as following:

$$Percent\ fruit\ damage = \frac{No.\,of immature\ damagefruit}{(No.\,Healthy + damagefruit)} X\ 100$$

Number of applications during the crop season

In CIM-496, ten applications of cypermethrin, deltamethrin and spinosad were given during each crop season from mid July to mid October. During the first crop season, one application in July (cypermethrin), four applications in August (two deltamethrin, one each cypermethrin and spinosad), in September, (two deltamethrin, one each cypermethrin and spinosad) and one application in October (spinosad) were given. During the second cop season, one application in July (cypermethrin), four applications in August (two deltamethrin, one each cypermethrin and spinosad) and in September three applications (one each deltamethrin, spinosad and cypermethrin) and two in October (deltamethrin and spinosad) were given.

Similarly in CIM-506, during 1st crop season ten applications, four applications in the month of August *i.e.* two application of deltamethrin, one each of cypermethrin and spinosad) and six applications in month of September *i.e.* three of cypermethrin, two of spinosad and one of deltamethrin were given for the control of *E. vittella* keeping below 1% TL. During the 2nd crop season nine applications, five applications in the month of August *i.e.* two each deltamethrin and spinosad and one cypermethrin) and four applications in the month of September *i.e.* two applications of cypermethrin and one each application of spinosad and deltamethrin were given.

Data analysis

Before subjected to analysis, the entire replicated data for fruiting parts only was transformed to running averages to synchronize the data with the help of following equation:

$$\textit{Running avearge} = \frac{\textit{1st Observation} + \textit{2nd observation}}{2}$$

Statistix 8.1v Software (Statistix, 2008) was used for statistical analysis. Split Plot ANOVA was used to determine the combined effect of the genotypes for number of fruits, damage, larval population and their interaction presented in Table I. Data for fruiting parts along with damages and larval population during study period was pooled and the mean of two years was analyzed with General ANOVA for working out the phenology *i.e.* the seasonal variation and means of damage and larval population for each genotype shown in Table II. Differences in percentages among damages as well as the larval populations were estimated by common mathematical equations to determine the larval survival rate or escapism from the insecticide applications, inevitable losses in total fruits and bolls. Damage compensation or tolerance was determined through the number of leftover bolls when the crop was harvested in October during 1st crop season and in November during 2nd season. For critical period of tolerance and rate of fruit consumption of *E. vittella* were graphically interpreted.

For calculation of percentage differences between the variables:

$$\%\text{ difference in variables (between treatments, genotypes etc)}$$
$$= \frac{\text{Value of 1st item} - \text{value of 2nd item}}{\text{Value of 1st item} + \text{value of 2nd item}} \times 100$$

RESULTS

Phenology of E. vittella *infestation*

ANOVA analyzed with split plot design is presented in Table I. *E. vittella* infestation (damage in fruits and larval population) was almost similar during both the crop seasons. However, the fruiting parts were significantly higher during 2nd season as compared to the 1st season. Both the genotypes *i.e.* CIM-496 and CIM-506 responded to *E. vittella* infestation in similar pattern except the fruiting parts as well as damage in mature fruits which were significantly different between both the genotypes. Treatments revealed significant differences in pest infestation and fruiting parts as well. However, no significant interaction was observed between the varieties and treatments.

Pest damage

The pest was active during the entire crop growth period. However, its damage and larval population responded significantly different in different months of the growing period. The most critical months were August and September in which the reproductive growth of the plant and pest infestation intensity were significantly higher. Figures 1 and 2 represent fruit damage caused by larvae. In immature fruits (IMF) including squares, flowers and small bolls, rate of fruit damage was higher during these two months of crop growth period as compared to mature bolls (MB). From Table II it was estimated at 4.5 and 4.1 IMF damaged by single larva in CIM-496 while 3.6 and 4.1 IMF in CIM-506 during August and September, respectively. Mature fruits (MB) were damaged at the rate of 1.5 and 1.6 per larva in the former genotype and 1.7 per larva in the later genotype. Overall damage per larva was ranged from 3 to 4 in total fruiting parts (TF) in both the genotypes. In October both, the rate of food consumption and infestation (the damage as well as larval population) were significantly reduced.

Table I.- Split plot ANOVA for varieties, treatments and varieties-treatment interaction.

Sources of variances and ANOVA		Immature fruits			Mature fruits			Total fruits		
		FP	Da	Lar	FP	Da	Lar	FP	Da	Lar
Years	F (1,2)	2.26	2.75	0.19	505.41	1.27	0.05	227.58	0.00	0.33
	P- values	0.27	0.24	0.71	0.002*	0.34	0.84	0.004*	1.00	0.62
Varieties	F (1,2)	61.78	0.69,	0.42	473.74	27.92	0.51	136.33	3.47	2.31
	P- values	0.016*	0.49	0.58	0.002*	0.034*	0.55	0.007*	0.20	0.27
Treatment	F (1,88)	2.27	48.51	38.53	7.13	43.32	44.05	8.52	59.89	60.21
	P- values	0.102	0.00*	0.00*	0.009*	0.00*	0.00*	0.004*	0.00*	0.00*
Var x Tret	F (1,88)	0.218	0.08	0.23	0.00	0.13	0.00	0.09	0.12	0.09
	P- values	0.67	0.77	0.63	0.97	0.72	0.95	0.76	0.73	0.77

FP, fruiting parts; Da, damage fruits; Lar, larval population.

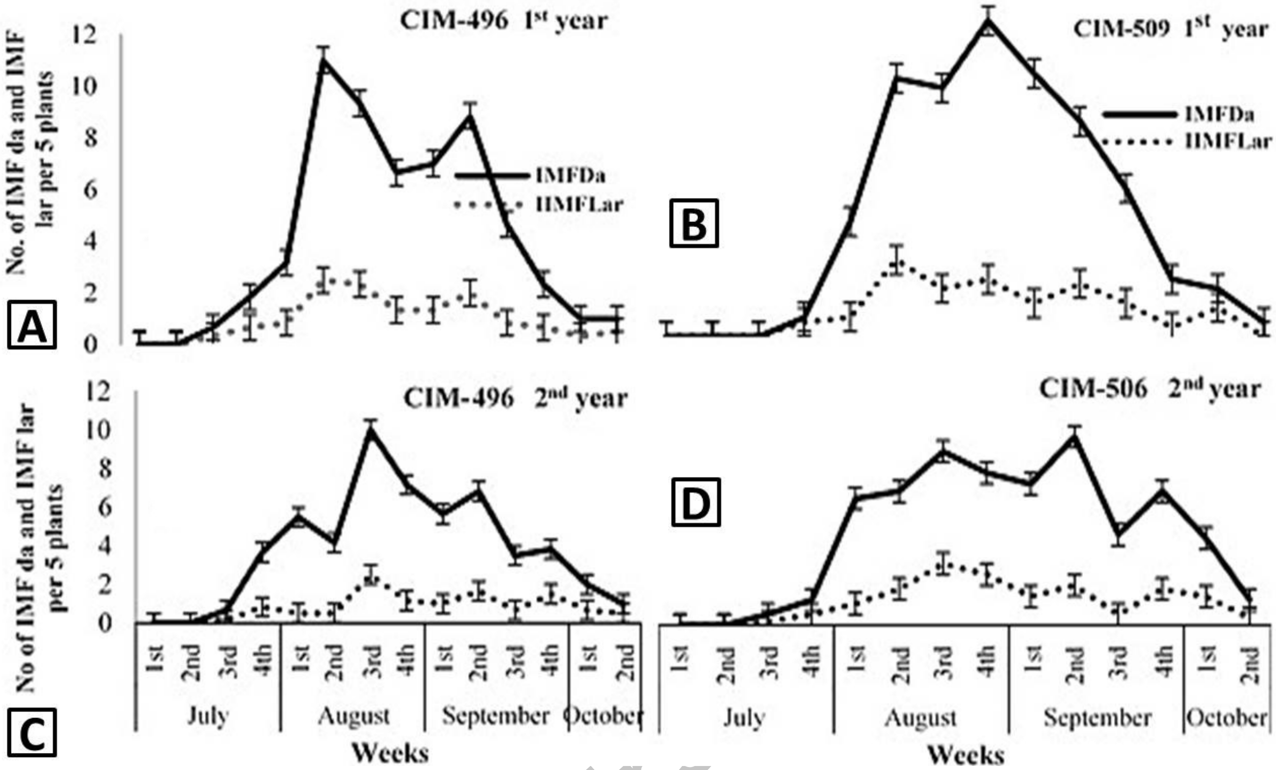

Fig. 1. Weekly trends of immature fruit damage (IMF Da) and larval population (IMF Lar). A and C, CIM-496; B and D, CIM-506.

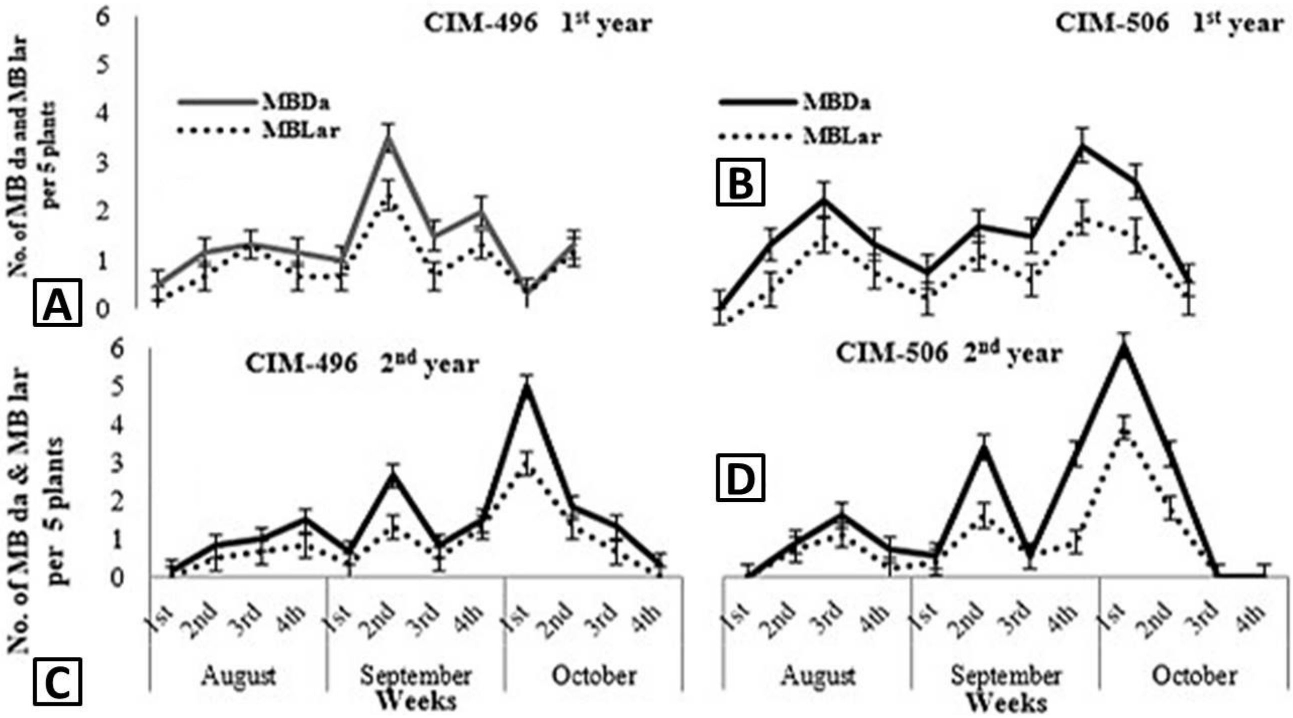

Fig. 2. Weekly trends of mature fruit damage (MB da) and larval population (MB lar). A and C, CIM-496; B and D, CIM-506.

The results further revealed that the rate of food consumption by *E. vittella* was slightly higher in August in CIM-496 while in September in CIM-506. Similarly IMF was more preferred by the larvae as compared to MB.

Impact of control measures on E. vittella *infestation*

The results in Table II reveal that 10 applications in CIM-496 and 9-10 applications in CIM-506 kept *E. vittella* infestation below 1% damage levels with significant increase in fruiting parts while reduction in *E. vittella* infestation when compared with untreated plots. In CIM-496, 22.1 % MB and 18.2 % TF were increased due to plant protection measures when 73.3% damage and 66.3% larval population was controlled. Similarly in CIM-506, 24.5% MB and 16.8% TF increased whereas 80.4% damage and 66% larval population were reduced. It is concluded that controlling the pest infestation up to 70-80% damage or 66% larval population, the yield might be increased by 22-24% in long or short duration genotypes.

Larval survival / escapism from the insecticide / inevitable losses

From Table II it was estimated that allowing upto 1% damage level, *E. vittella* caused 1.6-1.41 (0.8%) damage in IMF or 0.6-0.7 (0.3-0.4%) damage in MB that could not be controlled even with 10 applications in both the genotypes and were considered as inevitable losses. These losses were mostly ignored or not considered and cause slight miscalculation. These losses should be taken as correction factors at the time of estimation of ETL for *E. vittella*.

Table II.- Treatment and seasonal mean number of fruiting parts (FP), damage fruits (Da) and larval population (Lar) of *E. vittella* in immature (IMF), mature bolls (MB) for the genotypes (CIM-496) and (CIM-506) under unsprayed plots.

Source of variance	Treatments	Immature fruits (IMF)			Mature fruits (MB)			Total fruits (TF)		
		FP	Da	Lar	FP	Da	Lar	FP	Da	Lar
CIM-496										
Treatment	1%TL	200.9 a	1.6 b	0.8 b	189.3 a	0.6 b	0.4 b	390.2 a	2.13 b	1.15 b
	TL2	149.0 b	14.0 a	3.2 a	120.8 b	3.9 a	2.5 a	269.8 b	17.90 a	5.67 a
	% difference in T1 over T2				22.1			18.2	-73.3	**-66.3**
ANOVA	F (1,19)	53.10	23.94	6.91	19.56	28.12	31.55	36.75	0.88	40.27
	P-values	0.00	0.001	0.025	0.003	0.00	0.00	0.00	0.00	0.00
Months	July	83.9 c	2.0 b	0.7 b	5.7 c	0.05b	0.0 b	89.55 d	2.02 b	0.7 b
	August	308.9 a	15.4 a 4.5 / lar	3.4 a	104.4 b	2.2 a 1.5/ lar	1.5 a	413.3 b	17.62 a 3.7/ lar	4.8 a
	September	247.7 b	11.93 a 4.1/ lar	2.9a	250.2 a	3.9 a 1.6/ lar	2.4 a	497.9 a	15.78 a 3.0/ lar	5.3 a
	October	83.9 c	1.8 b 2.0/ lar	0.9 b	260.1a	2.9 a 1.5/ lar	1.9 a	319.4 c	4.65 b 1.7/ lar	2.7 b
ANOVA	F (3,19)	294.81	7.58	20.51	62.45	6.37	7.31	78.58	7.61	8.78
	P-values	0.00	0.016	0.02	0.00	0.003	0.002	0.000	0.002	0.007
CIM-506										
Treatment	1%TL	168.44 a	1.41 b	0.80 b	169.88 a	0.70 b	0.47 b	338.30 a	2.10b	1.23 b
	TL2	137.82 b	14.87 a	3.58 a	102.97 b	4.50 a	2.58 a	240.76 b	19.34a	6.14 a
	% difference in T1 over T2				24.5			16.8	-80.4	-66.0
ANOVA	F (1,19)	9.42	26.18	30.11	16.91	31.01	30.84	20.74	33.48	45.77
	P-values	0.0063	0.001	0.00	0.006	0.00	0.00	0.002	0.00	0.00
Months	July	36.48 c	0.60 b	0.30 b	0.43 c	0.00 c	0.00 b	36.92 d	0.60 b	0.30 c
	August	299.03 a	16.27 a 3.6/ lar	4.52 a	249.17a	2.45 b 1.7/ lar	1.47 a	371.07 b	18.70 a 3.13/ lar	5.98 a
	September	249.43 b	13.75 a 4.2/lar	3.27 a	224.02 a	4.65 a 1.7/ lar	2.57 a	498.57 a	18.37 a 3.17/ lar	5.80 a
	October	36.48 c	1.93 b 2.8/ lar	0.68 b	72.07 b	3.30 ab 1.6/ lar	2.05 a	251.57 c	5.22 b 1.9/ lar	2.72 b
ANOVA	F (3,19)	200.63	9.29	16.09	54.17	8.21	8.53	84.01	9.57	14.17
	P-values	0.00	0.005	0.00	0.00	0.001	0.009	0.00	0.005	0.00

Means followed by the same letter in a column are not significantly different at p=0.05.

Table III.- Mean number of unopened bolls (UOB open bolls (OB) and total bolls (TB) and % increase differences in treatments, years and varieties.

Genotypes, ANOVA and differences	1st year				2nd year			
	UOB		OB		UOB		OB	
	1%TL	TL2	1%TL	TL2	1%TL	TL2	1%TL	TL2
CIM-496	43.3 a	24.0 b	81.0 a	36.0 b	22.3 a	8.0 a	108.3 a	58.0 b
$F_{(1,2)}$ *P*-values	841.0 (0.0012)		141.28 (0.01)		16.51(0.056)		75.75 (0.013)	
1%TL % over TL2	28.7		38.5		47.2		30.2	
% Inc in Y2 over Y1	-32.0	-50.0	14.4	23.4				
CIM-506	13.0 a	12.7 a	83.0 a	37.0 b	0.3	0.3	99.0 a	48.3 b
$F_{(1,2)}$ *P*-values	0.02 (0.90)		396.75 (0.003)		0.01 (0.93)		3300.57 (0.003)	
1%TL % over TL2	1.2		38.3		0.0		34.4	
% Inc in Y2 over Y1	-95.5	-95.4	8.8	13.2				
% Inc. in V1 over V2	53.8%	30.8%	-1.2%	-1.4%	97.3%	92.8%	4.5%	9.1%

Means followed by the same letter in a column are not significantly different at p=0.05.

Similarly some of the larvae at 1% threshold level *i.e.* on an average of 0.8 larvae in IMF and 0.4-0.5 in MB were recorded during each observation. These larvae were alive damaging the crop. These larvae could therefore be considered as escaped from the insecticide applications.

Response of the cotton genotypes to E. vittela *infestation*

The responses of both the genotypes to *E. vittella* infestation were observed as critical period for tolerance during the crop growth periods and shown in Table III. Compensation at the time of harvest in total bolls (open (OB) and unopened bolls (UOB) is given in Table III.

Table III shows number of total fruiting parts per 5 plants per week plotted against 1% threshold level (1%TL) and unsprayed plots (TL2). The continuous lines represent fruiting pattern in 1%TL and dotted line for fruiting pattern in TL2.

In long duration genotype, CIM-496, both the continuous and doted lines run together from the month of July till the last week of August and started separating from each other in 1st week of September and the gap increased to a significant level till the time of harvest of the crop during both the year of study. The gap between these lines reveals the impact of insecticides as well as the response of the genotype to pest infestation. This long duration genotype CIM-496 tolerated the pest infestation till the last week of August and then the losses could not recover when *E. vittella* remained unchecked thereafter. The last week of August is the critical tolerance period for the long duration genotype CIM-496.

In short duration genotype of CIM-506, both the lines run together upto 2nd week of August and got separated afterword that continued till harvest. Similar situation was observed during second year of the study. The critical tolerance period of the short duration genotypes could be the second week of August.

The crop was harvested on 23rd October during 1st crop season and a month later on 23rd November during 2nd season, to determine year wise, treatment wise and varietal wise response of the short and long duration genotypes to *E. vittella* infestation. Table III reveals significant impact of control measures in percentage opening, and compensation percentage. In CIM-496, the impact of control measures could be observed on both the unopened (left over) and open bolls. In 1st crop season, 28.7 % UOB and 38.5 % OB were recorded whereas 47.2 % UOB and 30.2% OB in 2nd crop season were higher in 1%TL than in TL2. In CIM-506, only OB was taken into account and 38.5 % in 2009 and 34.4% in 2nd year were higher in 1%TL when compared with TL2. Very few leftover bolls (UOB) were observed with the negligible impact.

UOB was reduced by 32 and 50% while OB was increased by 14.4 and 23.4 % in CIM-496. OB was slightly increased by 8.8 and 13.2% in CIM-506 in 2nd crop season when compared with 1st crop season, respectively in both the treatments. The results further revealed that during 2009 UOB were higher by 53.8 and 30.8% but OB were lower by 1.2 and 1.4% in CIM-496 from CIM-506 when the crop was harvested in October. When the crop was harvested a month later in November during 2nd year, both UOB (97. 3 and 92.8%) and OB (4.5 and 9.1%) were increased in CIM-496 in both the treatments. Hence losses compensation was 4.5 and 9.1% higher in long duration genotypes as compared to short duration genotype in 1%TL (controlled) and TL2 (unsprayed conditions), respectively.

DISCUSSION

Impact of E. vittella *on cotton genotypes*

Both the genotypes *i.e.* CIM-496 and CIM-506 were peer susceptible to *E. vittella* by showing similar trend of fruits damaged and larval population. It might be due to the availability of nutrients and preference to both the genotypes. It is a published fact that preference and non preference to a crop species is estimated on the basis of quality of the crop and the availability of the nutrients (Sharma *et al*., 1982; Dhillon and Sharma, 2004). Moreover, *E. vittella* larvae had always showed higher tendency to G. *hirsutum* with trivial variation over the other cotton species like *G. arboreum* (Dhillon and Sharma, 2004; Razaq *et al*., 2004; Khan *et al*., 2007). So the unchecked pest in the present study was found to be the most serious to both genotypes and caused maximum of 79% of total fruits and 74% mature bolls in CIM-496 and 78.0% of total fruits and 83% mature bolls in CIM-506.

Infestation of the unchecked *E. vittella* was continued either as longer as with the plant life from 1st week of July till 4th week of October on CIM-496 or as shorter as from 3rd week of July till 1st week of October on CIM-506. However, the peak infestation period was between August and September. Broadly speaking, *E. vittella* incidence commenced when the crop was three weeks old, mostly in the month of July if sown in the month of May. Infestation of *E. vittella* mostly initiates with the development of reproductive parts of the plants and its population builds up with the effective boll development phase of crop (Baloch *et al*., 1990; Vennila *et al*., 2005).

August and September are the peak months for the fruit bearing (fructification) and *E. vittella* infestation. Significantly higher damage in immature fruits (IMF) as compared to damage in mature bolls (MB) was due to frequent attack by young larvae (1st to 3rd instars) in immature fruits. MB were damaged by full grown larvae (Srinivasan, 2001). It was further observed that once full grown larvae entered the bolls, these remained there till pre-pupation period. The field observation revealed that larvae of all stages were recorded in immature fruits, while full grown larvae were in the bolls only. These findings follow the observations made by Johnson and Zalucki (2007) who anticipated that young larvae have relatively higher growth rate and feed at more sites unlike the mature and full-grown larvae that fed at the selected sites (bolls). Early studies attributed for larval shifting to the change in abundance of fruit in each age class as the season progressed (Wilson and Waite, 1982; Raubenheimer and Browne, 2000; Vennila *et al*., 2007). In addition the degree of food utilization depends on the digestibility of food and the efficiency with which digested food is converted into biomass resulting higher growth rate in young larvae (Batista-Pereira *et al*., 2002). Such a larval distribution indicated the intra- specific competition among *E. vittella* larvae and the behavioral adjustment by frequent movements for their survival. This disproportionate of fruiting structure damage substantiated the behavioral adaptations in response to competition among *E. vittella* larval stages (Reed, 1994).

The spray regime in the present study was used as management tactics against *E. vittella* for both mid and short duration genotypes. In the former case, insecticide applications covered the period from mid July to mid October whereas in later case the crop period was August to September. Cypermethrin, deltamethrin and spinosad were found to be the most effective combination of insecticides with 72-86% larval control at 1% TL supporting the previous results of Pardeshi *et al*. (2009) and Dhaka and Prajapati (2013) with similar performance.

The least damaged fruits by few *E. vittella* larvae in 1% TL were inevitable / unavoidable losses as was termed by Mi *et al*. (1998), El-Heneidy *et al*. (2003) and Abhilash and Patil (2008). Similarly survival of larvae as full grown in the green bolls in 1% TL was considered as escaped from the insecticide applications and were assumed as resistant larvae because Ahmad and Arif (2009) and Jan *et al*. (2015) had already reported resistance in *E. vittella* against cypermethrin (42-123 fold), deltamethrin (17-31 fold) and spinosad (15-20 fold). However, there could also be some other reasons to larval survival in the present study. For instance expiration of the insecticide residual activity, timing of application, pest-dose-response phenomenon called Hormesis, occur in the pest populations exposed to sub lethal doses of pesticides (Hedin *et al*., 1988; Dutcher, 2007). The pattern of insecticide combinations and estimation of post application survival of the larvae in the current study suggested that the insecticides should be used in combination (on alternate basis) for effective control otherwise resistance may develop using these insecticides separately with repeated applications.

Higher number of larvae survived as full-grown in the bolls under unsprayed condition supports favorable environment and minimum number of natural enemies in the field for *E. vittella* population build up. Fye and Surber (1971) were of the opinion that natural mortality of bollworm eggs and early- stage larvae were caused due to unfavorable weather conditions such as wind, rain, and high temperatures, while King and Coleman (1989) and Kogan *et al*. (1989) also suggested the low level of actions of natural enemies in *E. vittella* larval mortality in the field condition.

Response of the cotton varieties to E. vittella *infestation*

CIM-496 expressed tolerance to *E. vittella* infestation in unsprayed condition till last week of August. Afterward significant decrease in the number of fruiting parts was observed in the month of September. Similarly delaying in harvest had a positive impact on this genotype. The crop retained and compensated the damaged fruits due to *E. vittella* infestation in terms of leftover or UOP bolls at the time of harvest. Ahmad and Malik (1996) reported that full season cotton varieties have primary and secondary fruiting cycles with the full season production scheme. The secondary fruiting cycle or top crop would begin in late August and continue to early October. Ahmad and Malik (1996) and Silvertooth (2015) also determined the potential of fruit retention for loss of early and late season fruit in full season cotton varieties resulting from poor management, bad weather and poor insect control. Management tactics for the genotypes like CIM-496 having the potential to tolerate the *E. vittella* infestation for longer period and can retain the damage fruits in late season of the crop must be initiated prior to the critical period of the crop. The crop protection measures could be started a week before the start of critical period. Third week of August should be the threshold period in which plant protection measures become mandatory. Control measures through chemicals in the late August to mid October are suggested to manipulate *E. vittella* infestation on such genotypes.

On the contrary, CIM-506 showed the tolerance to pest infestation till 1st week of August with significant reduction in the number of fruiting parts thereafter under unsprayed condition. Moreover early termination of the crop by mid October and negligible number of UOB at harvest time show limited potential of boll retention or compensation by the genotype for early fruit losses due to *E. vittella* infestation. Ahmad and Malik (1996) were of the opinion that short season and early maturing varieties mature before 1st week of October and cannot utilize the secondary flowering cycle to produce high yields of quality cotton at reduced cost. However, these varieties have little capacity to recuperate from biotic and abiotic stresses experienced during the season. Hence, Reed (1994) considered *Earias* spp. such as *E. insulana, E. vittella and E. biplaga* threat to short season cottons where significant populations are present early in the season of India and Pakistan and for short season genotypes like CIM-506 the critical fruiting period is August and September. Mandatory period for plant protection measures in short duration genotype should be the first week of August. Control measures through chemicals are suggested in the months of August and September for successful *E. vittella* management on short duration genotypes with lower management cost and higher quality cotton with broader options to the growers in terms of double-cropping possibilities (Silvertooth and Farr, 2001).

CONCLUSIONS

In the country like Pakistan where diverse climatic environment exists, cotton varieties can easily be grown with clearly known varietal characters and pest protection cost. Based on the results of current study, it is suggested that mid or full season varieties should be adopted where the late season pests and following crop are not the issue and the growers are satisfied with more yields of cotton seed. Similarly short season cotton will be adopted where late season pests like *P. gossypiella* and *H. armigera* are the serious problems and the growers are in a hurry to plant the next crops. Further *E. vittella* can be managed sensibly if the first and successive applications are given well in time and at proper intervals at levels other than 1% threshold levels depending upon the nature of the genotypes.

ACKNOWLEDGMENTS

We thank and acknowledg Dr. Zahid Mehmood, Director Central Cotton Research Institute, Multan and Mr. Muhammad Rafiq, Head Entomology, CCRI, Multan for their financial and technical support to conduct the trials. Dr. Muhammad Razaq from BZU Multan is appreciated for providing technical and moral support. This research was supported financially by the CCRI, Multan.

Statement of conflict of interest

The authors have declared no conflict of interest.

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