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Screening of USDA Cotton Accessions against Sucking Insect Pests Complex and Cotton Leaf Curl Virus (CLCuV) Disease with Major Emphasis on Abiotic Factors

Syed Ishfaq Ali Shah[1,*], Tassawar Hussain Malik[2], Imran Rafi Khan[1] and Zahid Hussain[3]

[1]*Central Cotton Research Institute (CCRI), Old Shujabad Road, Multan, Punjab, Pakistan*
[2]*Pakistan Central Cotton Committee (PCCC), Old Shujabad Road, Multan, Punjab, Pakistan*
[3]*The University of Agriculture, Peshawar, Khyber Pakhtunkhwa, Pakistan*

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SIAS conceived and designed the study and wrote the article. IRK analyzed the data. ZH interpreted the results.

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Abiotic factors, Cotton, Local varieties, Sucking insect pests complex, USDA accessions, Virus disease.

ABSTRACT

This study was conducted to evaluate the germplasms imported from United State Department of Agriculture (USDA), United State of America (USA) primarily for *Cotton leaf curl virus* (CLCuV) disease with promising local varieties tolerant to the disease. After screening, the most resistant accessions of USDA were USG-14-2464 and USG-14-2478. However, USG-14-2481 and USG-14-2484 were recorded as partially resistant to CLCuV disease. Among the local germplasms, all accessions screened were found extremely susceptible. Disease index increased with day after planting (DAP) and high infestation level of whiteflies as it was positive and non-significantly correlated with DAP and whitefly on both USDA accessions and local varieties. Maximum and minimum temperatures, rainfall and wind velocity were negative and non-significantly correlated while, % relative humidity (%R.H) was found non-significantly and positively correlated both with USDA accessions and local varieties. On overall basis, during the course of the season, lowest number of jassid/leaf was recorded on USG-12-8 (1.7) followed by USG-12-44 (3.2) and USG-12-24 (3.3) while, number of whiteflies/leaf on USG-14-2460 (11.6) followed by USG-12-24 (12.4) and USG-14-2478 (12.7) whereas, highest resistance was recorded against thrips in all accessions. Among the local varieties, lowest jassid/leaf was noted on desi/arborum (0.8) followed by AA-703 (3.6) and AA-802 (3.7) while, whitefly (12.8) and thrips (0.4) on desi cotton. The most sensitive planting date (DAP) of the crop for jassid both on USDA accessions and local varieties were 30 DAP (June-July), for whitefly 90 DAP (August-September) and partially only on local varieties, 30-60 DAP (June-August) for thrips. Maximum temperature and wind velocity promoted jassid population both on USDA and local varieties while, %R.H and rainfall decreased it. Maximum temperature and wind velocity decreased whitefly on USDA accessions whereas, these positively favored (increased) on local varieties. Increased in %R.H efficiently developed whitefly on USDA accessions while, non-significantly on the local varieties however, rainfall was found non-significantly positively correlated with USDA as well as local. Thrips increased with increase in maximum and minimum temperatures, rainfall and wind velocity on USDA and local varieties while, increase in %R.H resulted to promote thrips on USDA accessions while it declined on local varieties.

INTRODUCTION

The cotton having a share of 1.4% in GDP and 6.7% in agriculture value addition and is an important source of raw material to the textile industry. During 2013-2014, the crop was cultivated on an area of 2,806,000 hectares, 2.5% less than last year's area (2,879,000 hectares). The production stood at 12.8 million bales during the period 2013-14 against the target of 14.1 million bales, showed decline of 9.2% against the target and decline of 2.0% over the last year production of 13.0 million bales (PES, 2014). Decline in production has several reasons in which the insect pests are very important. According to Central Cotton Research Institute (CCRI), Multan a number of insect pests attack cotton crop in Pakistan, which cause 30-40% yield losses (CCRI, 2005).

Hoffmann *et al*. (1992), Wilson *et al*. (1992) and Jenkins (1994) viewed that *Bt* cotton will alter the arthropod community directly by reducing the abundance of *Helicoverpa* spp. and some other lepidopteron species.

* Corresponding author: sias337@yahoo.com
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The transgenic varieties possess toxic protein and they can effectively control specific lepidopterous species (Arshad *et al*., 2009) and unable to control sucking insect pests (Hofs *et al*., 2004; Sharma and Pampapathy, 2006). The reduction in the use of insecticides in *Bt* cotton can increase the population of sucking insect pests (Men *et al*., 2005) and hence sucking pests have become a more significant part of insect pest complex in *Bt* cotton (Wu *et al*., 2002). This is fact that genetically engineered cotton crop has successfully controlled bollworms but, it has adversely affected the sucking complex of cotton crop. With the increasing trend of transgenic cotton in Pakistan, the farmers are facing problems regarding sucking pest complex for which they have adopted intensive anti eco-friendly control methods. The simple method is being practiced in Pakistan for the control of insect pest, on which farmers frequently rely, is the chemical control (Arif *et al*., 2007). Use of chemical control is not only creating health hazards and ecological contamination but also growing the resistance in the insects and disturbing the balance between the forces of destruction (predators, parasitoids and pathogens) and forces of creation (biotic potential of pests) in agro-ecosystem (Ahmad and Khan, 1991; Hamburg and Guest, 1997; Sorejani, 1998). Chandani *et al.* (2015) viewed that insecticides should be environment friendly because, conventional pesticides are widely used to be controlled sucking complex but, these lead several serious problems like pest resistance, pest resurgence, secondary pest outbreak, pollutions, health hazards and destruction to eco-cycle, etc.

About 162 species of insect pests attack on various growth stages of cotton (Kannan *et al*., 2004). Amongst these species, cotton leafhopper, *Amarasca biguttula* (Ishida) (Hemiptera: Cicadellidae), tobacco whitefly, *Bemisia tabaci* (Gennadius) (Hemiptera: Aleyrodidae) and cotton thrips, *Thrips tabaci* Lindeman (Thysanoptera: Thripidae), are the important sucking insect pests. In these sucking pests, whitefly *i.e*. *B. tabaci* is the most notorious and key pest. Cotton whitefly constantly sucks the cell sap, resulting in 50% reduction in boll production, secretes honeydews on which sooty mold develops (Ahmad *et al*., 2002) and also acts as a vector of *Cotton leaf curl virus* (CLCuV) disease (Golding, 1930; Nelson *et al*., 1998). The average yield loss in Pakistan caused by CLCuV was reported 38.7% during 1993 by Khan and Khan (1995) which is threatening our cotton-based economy.

Jassid is polyphagus, much devastating and creates a considerable loss to the crop not only by sucking the cell sap but also by inducing toxic materials into the leaves, which cause a 4.45% reduction in the cotton yield (Bhat *et al*., 1986). The jassid caused a reduction of 114 kg of seed cotton yield/ha (Sidhu and Dhawan, 1986). Injury to plants is due to the loss of sap and probably also due to the infection of toxins. The attacked leaves turn pale and then rust-red. With change in appearance, the leaves also turn downwards, dry up and fall to the ground. Owing to the loss of plant vitality, the cotton bolls also drop off resulting in yield reduction (Panwar *et al*., 2014). It is the pest of economically important crops including agricultural and non-agricultural plants (Chandani *et al*., 2015).

Thrips is a serious pest on seedling cotton (Williams, 2006). The first sign of damage occurs on cotyledonary leaves, which take on a silvery appearance. Damaged true leaves become ragged and crinkled with damaged areas becoming more apparent as leaves expand. Severe damage causes loss of apical dominance and results in excessive branching with secondary terminals forming in leaf axils (Reed *et al*., 2001). A study in Pakistan revealed 37.6% loss in yield of seed cotton by combined attack of thrips (14.6 individuals/leaf) and jassid (4.6 individuals/leaf) (Attique and Ahmad, 1990).

In Pakistan, cotton production is stagnant for last two decades due to many biotic and abiotic stresses. Among these threats, the most damaging factor is CLCuV, which is responsible for huge losses in cotton production (Farooq *et al*., 2011). Cotton leaf curl, a viral disease of cotton, was reported for the first time in 1912 from Nigeria (Ferquharson, 1992). Later on, it was reported from Tanzania in 1926 (Jones and Mason, 1926) and from Sudan in 1934 (Bailey, 1934). In Pakistan, CLCuV disease was observed near Multan in 1967 (Hussain and Ali, 1975). The disease did not receive much attention in the beginning due to its casual occurrence and minor economic importance. Since 1987 it became a serious threat to Pakistan's cotton crop (Hussain and Mahmood, 1988). The disease-hit area was reported 97,580 hectares with a loss of 543,294 bales of cotton during 1992-93 seasons in the Punjab (GoP, 1992). The virus infected plants may show a variable range of symptoms depending on the intensity of the disease. Characteristic symptoms include yellowing and thickening of the small veins on the lower surface of young leaves and thickening of veins sometimes more pronounced in the form of upward and downward curling of leaves (Farooq *et al*., 2011). Under severe attack, the infected plants sometimes develop leaf enations (oval or cuplike foliar worth) on the underside of the leaf and plants become stunted and significant reduction in yield occurs (Ahmed *et al*., 2010).

Keeping in view the existing situation on cotton crop like sever outbreak of sucking insect pests complex on cotton especially the cotton whitefly with other secondary insects such as cotton stainer and dusky cotton bug on *Bt* cotton, CLCuV disease infection, indiscriminant application of insecticides which lead insect resistance problems, pollutions and health hazards. There is a direct need to develop an effective and eco-friendly pest management programme that is well suited not only to the ecological requirements, particularly the weather factors, which play a key role in the multiplication and distribution of insect-pests. Abiotic factors play a significant role in population fluctuation of insect pests (Murugan and Uthamasamy, 2001). The occurrence and progress of all the insect pests are much dependent upon the customary environmental factors such as temperature, relative humidity and precipitation (Aheer *et al*., 1994). The activities of these insect pests are fluctuated under erratic environmental conditions. For instance, jassid and whitefly exhibit their activity under wet environmental conditions whereas thrips and mites under high temperature dry situations (Khan and Ullah, 1994). This is why; detailed studies about the screening of plant resistance against sucking complex and CLCuV disease infection with relation to abiotic factors were planned. Plant resistance provides control of insect pests without any additional cost. It is also economical and environmentally safe (Pedigo, 1989; Khan and Saxena, 1998). By using resistant varieties, the pest population can easily be controlled without insecticide application (Hua and Hua, 2000). There are different physio-morphic traits of cotton varieties that inflict various tolerance/ resistance levels against the attack of sucking complex. Many previous researchers who found significant results of host plant resistance against sucking complex *i.e.* (Sontakke *et al*., 2000; Natwick *et al*., 2002; Nizamani *et al*., 2002). Likewise, Fairbanks *et al*. (1999) evaluated cotton varieties for comparative tolerance to thrips feeding in the field condition.

The present study was conducted as a part of the Pak-US Cotton Productivity Enhancement Programme (CPEP) financed by United State Agency for International Development (USAID), technically supervised by United State Department of Agriculture (USDA) and executed by International Centre for Agricultural Research in the Dry Areas (ICARDA) in Pakistan. Germplasm screening activities against potential insect pests, were carried out by the Department of Entomology, CCRI, Multan. The broad objectives of the study was to provide a complete road map to Plant Breeding and Genetics section for the development of new resistance strains against the sucking insect complex as well CLCuV disease. The specific objectives were as followed:

(i) Screening of USDA accessions including local promising verities against the incidence and development of sucking insect pests complex.

(ii) Screening resistant blood from USDA accessions with local varieties against the CLCuV disease for varietal development/improvement programme.

(iii) Impacts of abiotic factors on exotic accessions along with local varieties with emphasis of sucking insect complex incidence, development and CLCuV disease with different intervals *i.e.* 30, 60 90 and 120 DAP.

Breeders all over Pakistan made efforts to develop CLCuV disease resistant varieties to combat this disease using various breeding techniques, however, these varieties became susceptible after 2-3 years (Saeed *et al*., 2014). According to Li *et al*. (2008) for obtaining superior genotypes proper exploitation of available germplasms in the form of hybridization and addition of new germplasms are necessary to create sufficient genetic variation. Variability in germplasms not only increase the chances of multiple resistance against biotic and abiotic stresses but, also yield desirable combinations that can be utilized in future breeding programmes (van Esbroeck and Bowman, 1998). It is fact that weather parameters vary greatly from place to place and season to season. Therefore, the knowledge of the influence of weather parameters on sucking insect complex on newly imported USDA accessions with comparison of local varieties will help in efficient screening. Moreover, such studies regarding the promising local varieties will warn the farmers about the seasonal incidence and development of sucking complex with relation to its abiotic factors will be helpful for devising pre-planned management strategies against the sucking pests.

MATERIALS AND METHODS

Total of selected 19 accessions, imported from United State were sown with seven local promising varieties, *i.e.* CIM-446, CIM-496, AA-703, AA-802, MNH-886, CIM-599 and Desi cotton, *Gossypium arboreum* in the Department of Entomology, CCRI, Multan on June 13, 2014. Late sowing was preferred intentionally to assure the onset of ideal environment to CLCuV disease infection development in all exotic and native genotypes. Early planting was usually considered to “Ecape” the infection during previous studies. Due to short United State Department of Agriculture (USDA) stock of germplasms, each treatment (had no replication), plot size was 1.83 m X 2.29 m with plant to plant distance 0.30 m and row to row was 0.76 m maintained. All agronomical practices were kept standard during the whole course of experiment. Sucking insect pests were encouraged to develop but, jassid and whitefly population were flared up to injury level 34 and 67 DAP, respectively. That is why chemical applications were made to decline pests from economic injury level to (EIL) to economic threshold level ETL.

For sucking pests population density per leaf, five plants of each USDA accession and local variety were tagged randomly and data were recorded from them at 30, 60, 90 and 120 DAP. The leaves were observed in such a way that one leaf each from upper, middle and bottom part of the tagged plants. CLCuV disease index (DI) of tagged plants also recorded at 60, 90 and 120 DAP with the coordination of Plant Pathology Section, CCRI, Multan. Recorded data were analyzed with repeated measure ANOVA and mean comparison was done with Tukey's HSD test (Oehlert, 2010). Disease index were calculated by using the following formula:

$$\textit{Disease index (DI)} = \textit{(\% Disease)} \times \textit{(Disease severity)} \; [4 \textit{ (maximum severity level)}]^{-1}$$

The concerned meteorological data provided by the directorate of CCRI, Multan of maximum and minimum temperatures (˚C), %R.H, wind velocity (km/hr) and average rainfall (mm) at 30, 60, 90 and 120 DAP. Mean (each 30 days interval) of abiotic factors were calculated and compared with sucking pest complex infestation and CLCuV disease infection. Economic Threshold Level of the pests and symptoms of disease severity of CLCuV disease were followed as: Jassid (1 nymph or adult/leaf), whitefly (4-5 nymphs or adults/leaf), and thrips (8-10 nymphs or adults /leaf) (Table I).

Table I.- Rating scale for CLCuV disease symptoms.

Symptoms	Disease severity	Disease reactions
No symptom	0	Resistant
Thickening of only secondary and tertiary veins	1	Highly tolerant
Thickening of tertiary veins, secondary and primary veins	2	Tolerant
Vein thickening	3	Susceptible
Stunting alone with, vein thickening leaf curl/enation	4	Highly susceptible

RESULTS

Abiotic factors

Mean maximum, minimum temperature, %R.H, rainfall and wind velocity were 37.81˚C, 30.41˚C, 58.56%, 0.25 mm and 8.72 km/hr, respectively at 30 DAP. They were 36.69˚C, 29.47˚C, 66.89%, 1.48 mm and 6.79 km/hr at 60 DAP, 34.70˚C, 26.90˚C, 72.83%, 0.61 mm and 5.13 km/hr at 90 DAP while, 32.54˚C, 22.77˚C, 74.12%, 0.68 mm and 3.41 km/hr at 120 DAP (Fig. 1).

Population development of sucking complex

Mean Jassid/leaf on all nineteen USDA accessions at 30 DAP was significantly higher (2.38±0.30) as compared to 60, 90, and 120 DAP whereas, lowest population (0.67±0.13) was observed at 90 DAP followed by 0.75±0.08 at 60 DAP. Mean pest population at 60, 90 and 120 DAP was statistically same (Fig. 1). For mean comparison, Tukey's HSD value at 1% for USDA accessions was 0.87.

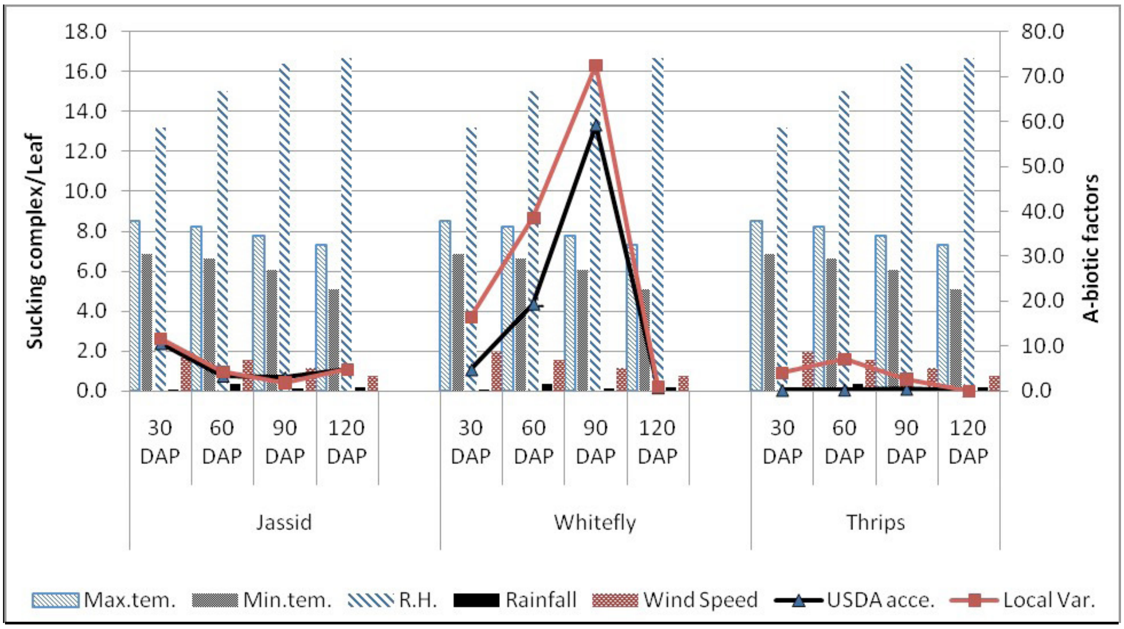

Fig. 1. Number of sucking insect complex per leaf on 30, 60, 90 and 120 DAP on USDA imported accessions versus local varieties with relation to abiotic factors.

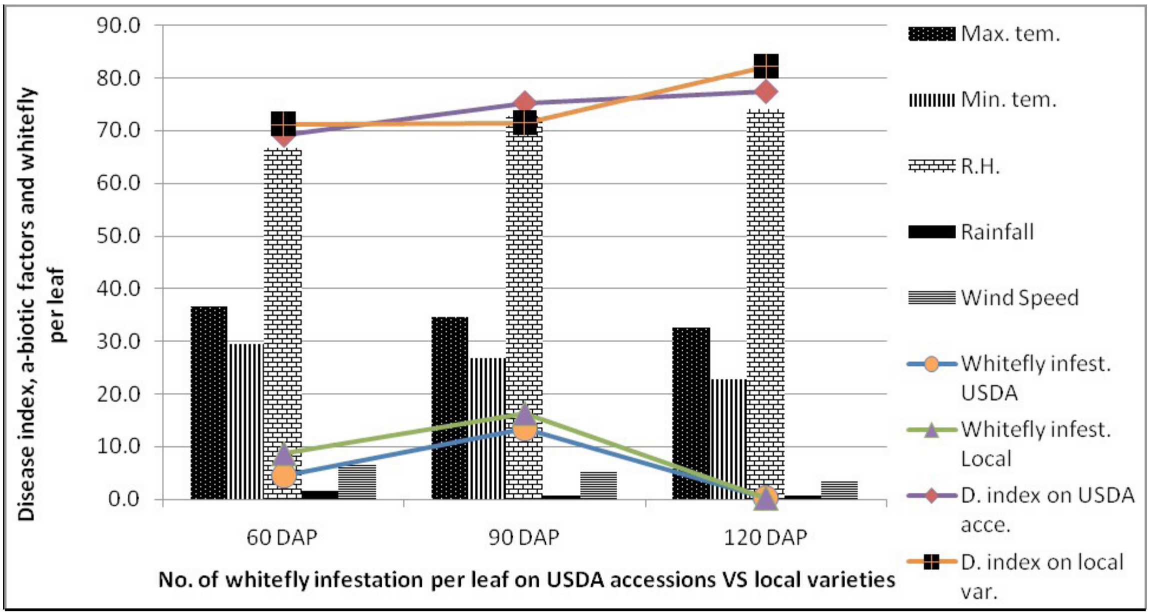

Fig. 2. Shows CLCuV disease index on 30, 60, 90 and 120 DAP of USDA imported accessions verses local varieties with correlation of abiotic factors. infest, infestation; ace, accessions; var, varieties.

Mean jassid/leaf on seven local varieties at 30 DAP was significantly higher (2.61±0.58) as compared to 60, 90, and 120 DAP while, lowest (0.41±0.09) at 90 DAP followed by 0.96±0.22 at 60 DAP (statistically same). Tukey’s HSD value at 1% for mean comparison of local varieties was 1.22 (Fig. 1).

Significantly maximum (13.33±1.43) mean whitefly population was observed on all USDA accessions at 90 DAP as compared to 30, 60, and 120 DAP, respectively while, significantly lowest (0.16±0.05) at 120 DAP followed by 1.07±0.25 at 30 DAP (statistically at par) (Fig. 1). Tukey’s HSD value at 1% was 3.47.

Significantly highest mean whitefly population (16.31±3.14) was recorded on all local varieties at 90 DAP as compared to 30 and 120 DAP (statistically same) while lowest 0.20±0.03 at 120 DAP followed by 3.70±0.76 at 30 DAP (statistically same) (Fig. 1). Tukey’s HSD value at 1% was 8.89.

Thrips population remained at low level throughout the season on all nineteen USDA accessions and found nonsignificant to each other at 30 DAP (0.04±0.02), 60 DAP (0.05±0.03), 90 DAP (0.09±0.07) and 120 DAP (0.0±0.0). Mean thrips/leaf on all seven local varieties were also at low level and recorded nonsignificant to each other at 30 DAP (0.90±0.70), 60 DAP (1.59±0.46), 90 DAP (0.59±0.59) and 120 DAP (0.0±0.0) (Fig. 1).

Status of CLCuV disease index with whitefly population

Mean whitefly population (on all 19 USDA accessions) was recorded at 60, 90 and 120 DAP 4.36±0.36, 13.33±1.43 and 0.16±0.05, respectively. Significantly highest CLCuV disease index (78.59±13.85) was recorded on all 19 USDA accessions was recorded at 120 DAP as compared to 60 DAP 70.28±12.0 (Fig. 2). Disease index at 90 DAP was 76.52±12.1 which was statistically same with 60 and 120 DAP. Tukey’s HSD value at 1% was 7.03.

Mean whitefly numbers (on all local varieties) was observed at 60, 90 and 120 DAP 8.67±1.33, 16.31±3.14 and 0.20±0.03, respectively (Fig. 2). While, mean significantly highest CLCuV disease index 82.20±13.85 on all seven local varieties was recorded at 120 DAP as compared to 90 DAP (71.60±12.08) and 60 DAP (71.27±12.04) (Fig. 2). Tukey’s HSD value at 1% was 9.95.

Jassid incidence and development

At 30 DAP highest jassid/leaf on USDA accessions was found on USG-14-2459 (5.30) followed by USG-14-2463 (4.60) and on local varieties MNH-886 (4.80) followed by CIM-599 (4.30). It was lowest on USG-12-8 (0.40) followed by USG-12-44 (0.50) while, on local varieties, it was lowest on desi cotton (0.40) followed by AA-703 and AA-802 (1.70) (Fig. 3).

On USDA accessions maximum jassid/leaf at 60 DAP was found on USG-14-2459 (1.40) followed by USG-14-2464 (1.30) and on local varieties CIM-599 (2.00) followed by MNH-886 (1.50) while, minimum on USG-12-24 (0.20) followed by USG-12-108 and USG-14-2478 (0.30) respectively and on local, desi cotton and AA-802

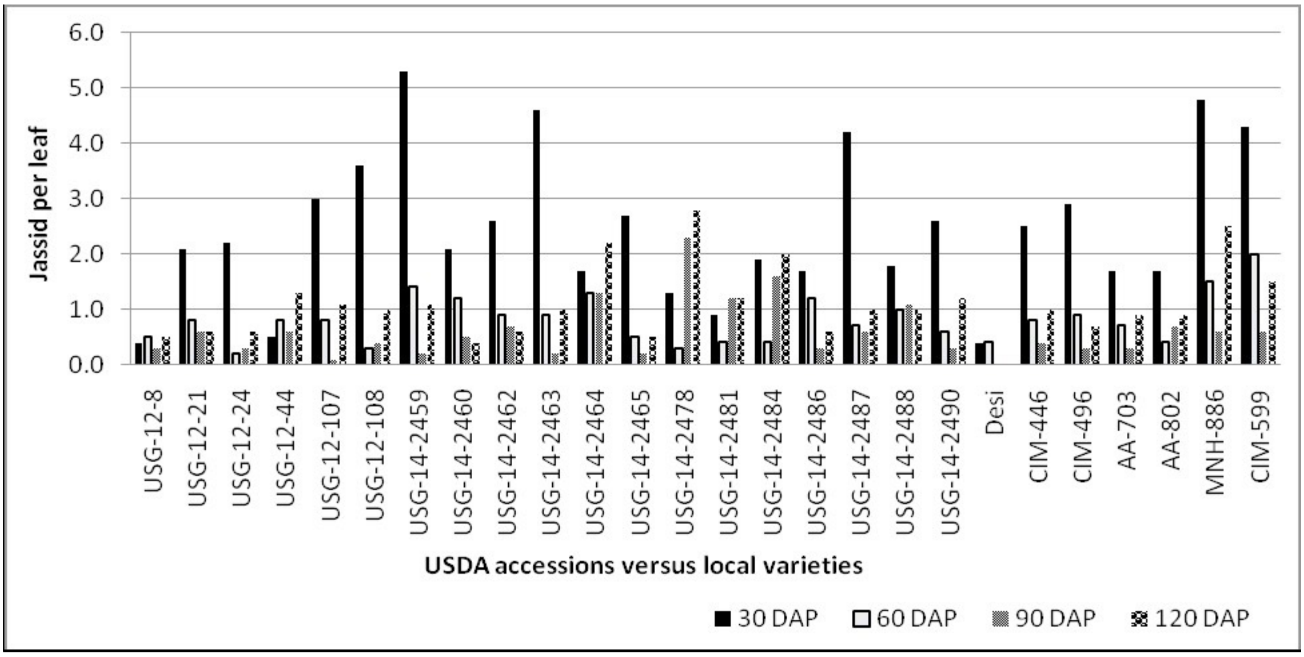

Fig. 3. Mean number of jassid infestation per leaf on USDA imported accessions versus local varieties with interval of 30, 60, 90 and 120 DAP.

(0.40) followed by AA-703 (0.70) (Fig. 3).

At 90 DAP highest jassid/leaf on USDA accessions was found on USG-14-2478 (2.30) followed by USG-14-2484 (1.60) and on local varieties AA-802 (0.70) followed by MNH-886 and CIM-599 (0.60). Lowest pest numbers was recorded on USG-12-107 (0.10) followed by USG-14-2459, USG-14-2463 and USG-14-2465 (0.20) while, on local varieties, CIM-496 and AA-703 (0.30) followed by CIM-446 (0.40). Zero jassid/leaf was recorded on desi cotton (Fig. 3).

At 120 DAP highest jassid/leaf on USDA accession was recorded on USG-14-2478 (2.80) followed by USG-14-2464 (2.20) and on local varieties MNH-886 (2.50) followed by CIM-599 (1.50) while, lowest on USG-14-2460 (0.40) followed by USG-12-8 and USG-14-2465 (0.50). Among the local varieties, it was lowest on CIM-496 (0.70) followed by AA-703 and AA-802 (0.90). Zero population of jassid/leaf recorded on desi cotton (Fig. 3).

Whitefly incidence and development

At 30 DAP highest whitefly/leaf on USDA accessions was recorded on USG-14-2462 (4.20) followed by USG-12-107 (3.0) while, on local varieties, MNH-886 (6.70) followed by CIM-496 (6.00). It was lowest on USG-14-2463 and USG-14-2486 (0.20) followed by USG-14-2478 (0.30) whereas, on local varieties, it was minimum on CIM-446 (1.00) followed by desi cotton (2.40) (Fig. 4).

At 60 DAP, zero population of whitefly/leaf was recorded on USG-12-108. Maximum whitefly/leaf on USDA accessions was found on USG-12-21 (8.70) followed by USG-12-44 (7.30) and on local varieties, on AA-802 (15.20) followed by MNH-886 (10.50). Minimum pest number was recorded on USG-14-2488 (1.70) followed by USG-14-2464 (2.80) while on local varieties, on CIM-599 (4.80) followed by desi cotton (5.10) (Fig. 4).

At 90 DAP highest whitefly/leaf on USDA accessions was found on USG-14-2481 (28.90) followed by USG-12-44 (21.30) and on local varieties, on CIM-599 (28.00) followed by AA-802 (23.50). Lowest population was recorded on USG-14-2462 (4.70) followed by USG-12-107 (5.50) and on local varieties, on desi cotton (4.80) followed by MNH-886 (7.80) (Fig. 4).

Highest whitefly/leaf at 120 DAP on USDA accession was found on USG-12-44 (0.80) followed by USG-12-21 and USG-12-24 (0.50) while, lowest on USG-12-107, USG-12-108, USG-14-2462, USG-14-2465, USG-14-2486 and USG-14-2490 (0.10), respectively followed by USG-14-2463 and USG-14-2487 (0.20) (Fig. 4). On USG-14-88 whitefly/leaf was recorded (0.30) while rest of all was found free from whitefly. Highest whitefly/leaf of local varieties was recorded on CIM-496 and AA-703 (0.30), respectively followed by desi cotton, AA-802, MNH-886 (0.20) and CIM-446 and CIM-599 (0.10), respectively (Fig. 4).

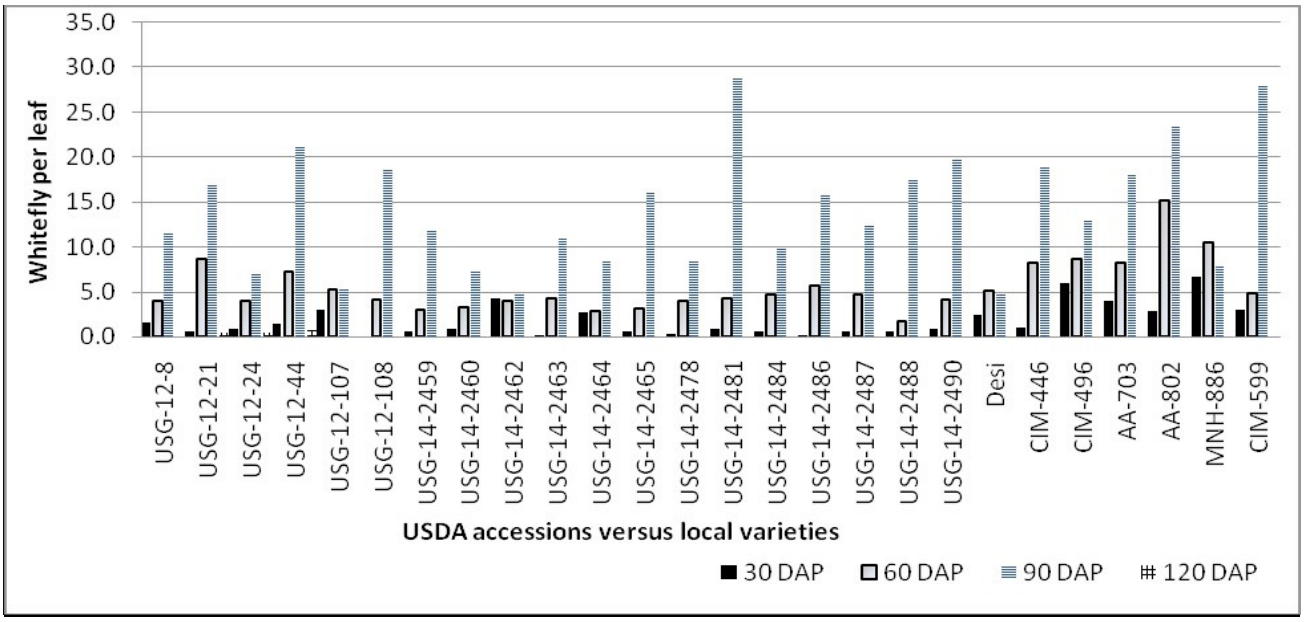

Fig. 4. Mean number of whitefly infestation per leaf on USDA imported accessions versus local varieties with interval of 30, 60, 90 and 120 DAP.

Thrips incidence and development

Thrips remained below threshold level throughout the study period on all the testing accessions and varieties. At 30 DAP, zero thrips/leaf was recorded on all accessions/ varieties except USG-12-8 (0.30) and USG-12-21 and USG-12-24 (0.20), CIM-599 (5.00), CIM-496 (1.10) and CIM-446 (0.20) (Fig. 5).

On USDA accessions at 60 DAP it was recorded only on USG-14-2465 and USG-14-2484 (0.30) on USG-14-2478 (0.40). Highest thrips population/leaf on local varieties was recorded on AA-802 (3.30) followed by MNH-886 (2.70) while, lowest on desi cotton (0.40) followed by CIM-496 (0.90) (Fig. 5).

At 90 DAP on USDA accessions it was recorded only on USG-14-2460, USG-14-2464 and USG-14-2486 (0.30), (0.10) and (1.30), respectively. Highest thrips/leaf was recorded on local varieties MNH-886 (2.30) followed by CIM-446 (1.30), AA-802 (0.40) and CIM-599 (0.10) (Fig. 5).

Zero thrips/leaf on USDA accessions as well as on local varieties were recorded at 120 DAP (Fig. 5).

Correlation among population development of sucking insects, DAP, CLCuV disease index and abiotic factors

USDA accessions

Correlation among overall mean (*i.e.* 30, 60, 90 and 120 DAP) jassid, whitefly and thrip per leaf, overall mean DAP, mean disease index and abiotic factors were compared.

Jassid was highly significant and negative correlated with DAP, whitefly and disease index while, non-significant negative with thrips. Among the abiotic factors, all were recorded highly significant correlated except minimum temperature which was significantly positive. Relative humidity (%) and rainfall were negative while, maximum, minimum temperatures and wind velocity with positively correlated (Table II).

Whitefly was non-significantly positive correlated with DAP, thrips and disease index. It was found highly significant positive correlation with % R.H and non-significant with the rest of abiotic factors. Maximum temperature and wind velocity had negatively while, minimum temperature and rainfall were positively correlated (Table II).

Thrips was non-significantly negative correlated with DAP, jassid and disease index. It was non-significant positive correlation with all abiotic factors (Table II).

Local varieties

Jassid was highly significant and negatively correlated with DAP, non-significant negative with whitefly and thrips (positive) while, significantly positive with disease index. Among the abiotic factors, it was high significantly, negative correlated with %R.H and wind velocity (positive) while, significant positive with maximum temperature, non-significant with minimum (positive) and significantly negative with rainfall (Table III).

Whitefly was recorded non-significantly negative correlated with DAP and positive with thrips/leaf and disease index. All abiotic factors were non-significantly positive correlated with whitefly/leaf (Table III).

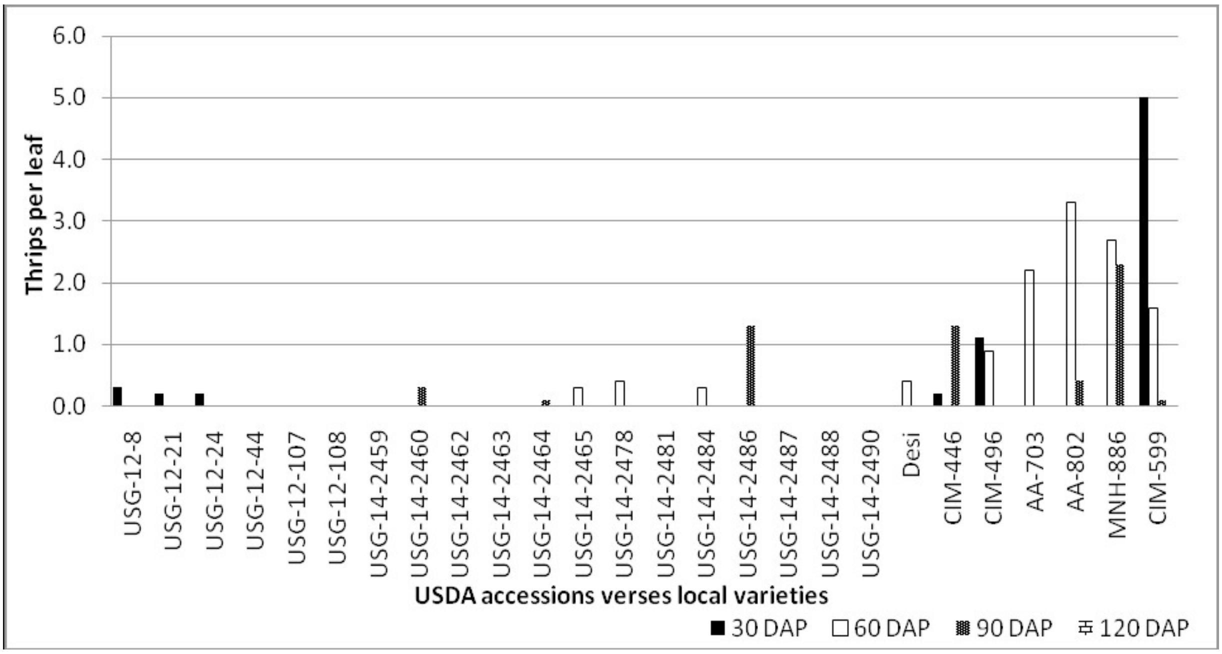

Fig. 5. Mean number of thrips infestation per leaf on USDA imported accessions versus local varieties with interval of 30, 60, 90 and 120 DAP.

Table II.- Correlation among sucking complex, days after planting, disease index and abiotic factors on USDA imported accessions.

	Mean of 30, 60, 90 and 120 DAP								
	DAP	Jassid	Whitefly	Thrips	D. index	Max. Tem.	Min. Tem.	%R.H.	Rainfall
Jassid	-0.42**								
Whitefly	0.12	-0.33**							
Thrips	-0.05	-0.16	0.16						
D. index	0.10	-0.57**	0.02	-0.06					
Max.tem.	-0.99**	0.35**	-0.05	0.07	-0.10				
Min.tem.	-0.96**	0.27*	0.07	0.09	-0.09	0.99**			
%R.H	0.96**	-0.54**	0.32**	0.002	0.10	-0.91**	-0.84**		
Rainfall	0.10	-0.45**	0.06	0.02	-0.10	0.01	0.08	0.25*	
W. speed	-0.10**	0.44**	-0.12	0.05	-0.05	0.99**	0.96**	-0.96**	-0.13

Where, *= Significant at P ≤ 0.05; **= Significant at P ≤ 0.01. DAP, day after planting; D. index, disease index; Max. Tem, maximum temperature; Min. Tem.; minimum temperature, R.H., Relative humidity.

Thrips was recorded non-significantly negative correlated with DAP, positive with jassid/leaf and disease index. Among the abiotic factors, maximum and minimum temperatures were recorded significantly positive while, negative non-significant with %R.H and positive with rainfall and wind velocity (Table III).

Percent disease and disease severity at 60, 90 and 120 DAP

On USDA accessions, CLCuV disease was recorded with 0, 3 and 4 severity levels. Symptoms and disease reactions against the disease severity are mentioned in the materials and methods chapter (Table I). USG-14-2464 and USG-14-2478 were found completely disease free at 60, 90 and 120 DAP while, USG-14-2484 and USG-14-2481 were recorded 5.60% and 25% at 60 DAP, 8.80% and 35% at 90 DAP and 9.10% and 50%, respectively at 120 DAP however, USG-14-2462 was recorded 74% at 60 DAP and 100% at 90 and 120 DAP. Rest of all USDA accessions were recorded 100% diseased even at 60 DAP (Table IV).

Table III.- Correlation among sucking complex with DAP, CLCuV disease index and abiotic factors of local varieties.

	Mean of 30, 60, 90 and 120 DAP								
	DAP	Jassid	Whitefly	Thrips	D. index	Max. Tem.	Min. Tem.	%R.H.	Rainfall
Jassid	-0.49**								
Whitefly	-0.04	-0.28							
Thrips	-0.33	0.28	0.14						
D. index	0.14	0.48*	0.13	0.11					
Max.tem.	-0.99**	0.42*	0.12	0.37*	-0.14				
Min.tem.	-0.96**	0.34	0.23	0.39*	-0.15	0.99**			
%R.H	0.96**	-0.61**	0.18	-0.25	0.11	-0.91**	-0.84**		
Rainfall	0.10	-0.36*	0.15	0.27	-0.07	0.01	0.08	0.25	
W. speed	-0.10**	0.50**	0.03	0.32	-0.14	0.99	0.96**	-0.96**	-0.13

For statistical details and abbreviations see Table II.

Table IV.- Shows CLCuV disease percentage and severity of USDA accessions.

Accessions	% disease			Disease severity		
	60 DAP	90 DAP	120 DAP	60 DAP	90 DAP	120 DAP
USG-12-8	100	100	100	4	4	4
USG-12-21	100	100	100	4	4	4
USG-12-24	100	100	100	4	4	4
USG-12-44	100	100	100	3	4	4
USG-12-107	100	100	100	3	4	4
USG-12-108	100	100	100	4	4	4
USG-14-2459	100	100	100	3	4	4
USG-14-2460	100	100	100	3	3	3
USG-14-2462	74	100	100	3	4	4
USG-14-2463	100	100	100	4	4	4
USG-14-2464	0	0	0	0	0	0
USG-14-2465	100	100	100	3	3	3
USG-14-2478	0	0	0	0	0	0
USG-14-2481	25	35	50	3	3	4
USG-14-2484	5.60	8.80	9.10	3	3	3
USG-14-2486	100	100	100	4	4	4
USG-14-2487	100	100	100	4	4	4
USG-14-2488	100	100	100	3	4	4
USG-14-2490	100	100	100	3	4	4

Among the local varieties, only desi cotton variety was recorded disease free while rests of all varieties were found with 100% diseased even at 60 DAP (Table V).

Overall seasonal population development of sucking insect pests on USDA versus local varieties

These findings were based on the collective sum *i.e.* 30, 60, 90 and 120 DAP infestation of jassid, whitefly and thrips per leaf.

Highest jassid/leaf was recorded on USG-14-2459 (8.0) followed by USG-14-2463 and USG-14-2478 (6.7) whereas, lowest number of jassid/leaf was on USG-12-8 (1.7) followed by USG-12-44 (3.2) and USG-12-24 (3.3) (Fig. 6). Among the local varieties its highest population was recorded on MNH-886 (9.4) followed by CIM-599 (8.4) while, lowest on desi cotton (0.8) followed by AA-703 (3.6) and AA-802 (3.7) (Fig. 6).

Table V.- Shows CLCuV disease percentage and severity of local varieties.

Varieties	% disease			Disease severity		
	60 DAP	90 DAP	120 DAP	60 DAP	90 DAP	120 DAP
Desi cotton	0	0	0	0	0	0
CIM-446	100	100	100	3	4	4
CIM-496	100	100	100	4	4	4
AA-703	100	100	100	3	4	4
AA-802	100	100	100	3	3	4
MNH-886	100	100	100	3	3	4
CIM-599	100	100	100	3	3	4

Highest whitefly/leaf was recorded on USG-14-2481 (33.9) followed by USG-12-44 (30.8) while, lowest pest number was on USG-14-2460 (11.6) followed by USG-12-24 (12.4) and USG-14-2478 (12.7) (Fig. 6). Among the local varieties, maximum pest population was recorded on AA-802 (41.8) followed by CIM-599 (35.9) while minimum on desi cotton (12.8) followed by MNH-886 (25.2) (Fig. 6).

All 19 USDA accessions were recorded highly resistant against thrips population as only USG-14-2486 was recorded with 1.3 (Fig. 6). Among the local varieties,

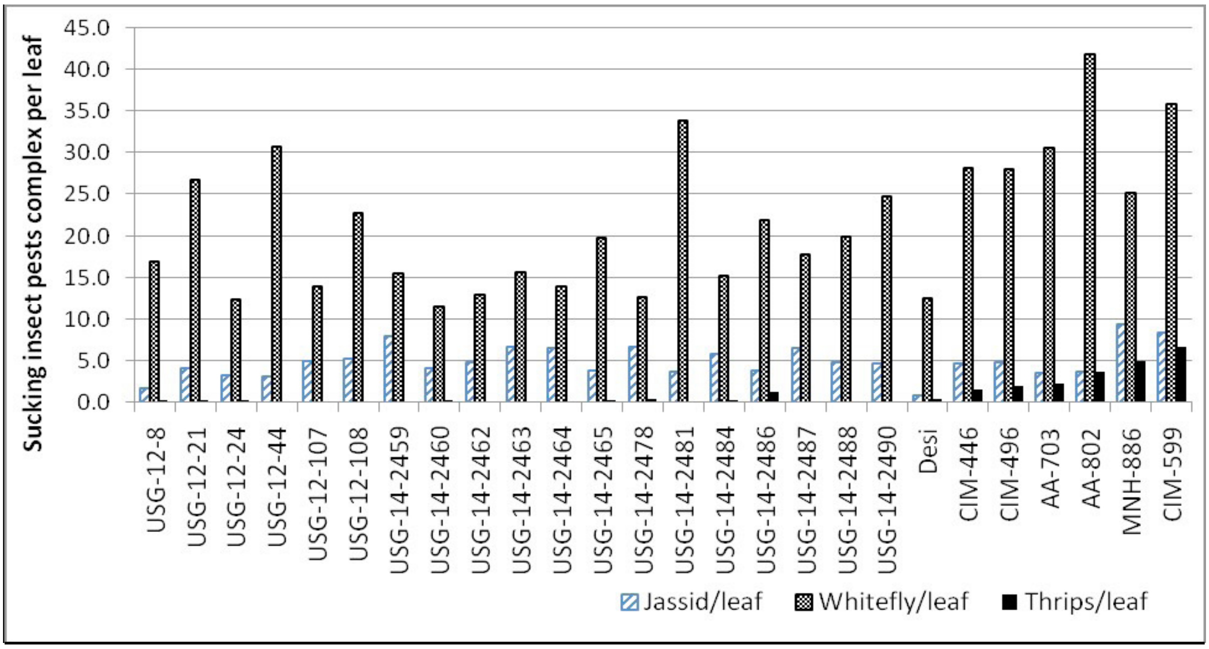

Fig. 6. Total number of jassid, whitefly and thrips per leaf at 30, 60, 90 and 120 DAP on USAD accessions versus local varieties.

it was maximum on MNH-886 (6.7/leaf) followed by CIM-599 (5.0/Leaf) while, comparatively less number of thrips was recorded on rest of the varieties.

DISCUSSION

Population development trend of sucking insects and its correlation with DAP, disease index and abiotic factors

Cotton leafhopper is polyphagous pest found throughout the year on cotton, brinjal and China rose but it migrate to various crops for its survival and cause considerable damage to various economically important crops. Hence its eco friendly control is needed (Chandani *et al*., 2015). In this context, we evaluated USDA accessions verses local varieties against the sucking pest complex for the development of resistant strains. Meteorological parameters play an important role in the population fluctuation of sucking insect pests (Gogoi and Datta, 2000; Murugan and Uthamasamy, 2001; Panickar and Patel, 2001). The most important abiotic factor is temperature, which has dominant role in pest population variation (Bale *et al*., 2002).

Same population development trend of jassid on USDA accessions and local varieties was observed at 30, 60, 90 and 120 DAP (Fig. 1). Most critical period for USDA accessions as well as local varieties were noticed at 30 DAP when maximum jassid/leaf was recorded as compared to 60, 90 and 120 DAP. According to our findings, jassid mostly preferred vegetative stages of all testing strains (Fig. 1; Tables II and III) that DAP was negative and significantly higher correlated with jassid population. Another aspect of preference and non-preference of jassid to cotton crop was observed with correlation factor of whitefly and CLCuV disease. Jassid was found negative and significantly higher with whitefly population and CLCuV disease on USDA accessions and it was negative, non-significant with whitefly and significantly positive with disease index on local varieties. According to Figure 1, highest abundance of jassid and whitefly were noticed at 30 DAP on both USDA accessions and local varieties with downward trend of maximum and minimum temperatures and upward trend of %R.H onward to 120 DAP. At 90 DAP whitefly population was at peak and jassid declined while, downward trend of whitefly was recorded at 120 DAP as jassids again depicted an upward trend with even peaked %R.H (negative and significantly higher with jassid). Both the nymphs and adults of jassid suck sap from the leaves (Panwar *et al*., 2014). It means that jassid avoided disease affected and sooty mold cotton crop as whitefly causes indirect damage to cotton by transmitting CLCuV (Nelson, 1991) that sucks plant sap and secreting honey dews (Ali and Aheer, 2007) which ultimately hampers plant's photosynthetic activities due to the development of sooty mold (Aslam *et al*., 2001). As far as the correlation of jassid with disease index on local varieties is concerned, it was contradictory with the USDA accessions because of the native germplasms that were preferred native jassids as USDA accessions were new for the native.

On USDA accessions, maximum temperature and wind velocity significantly increased the jassid population as these were found highly significant and positively correlated (Tables I and II). Highest % R.H. and rainfall significantly decreased jassid population on USDA accessions as these were highly significant and negatively correlated (Tables I and II). Mean maximum and minimum temperatures were found as positive and significantly correlated with population change of jassid (Chandani *et al*., 2015). Results regarding the correlation of temperature with jassid are in agreement with those of Cowland (1947), Wahla *et al*. (1996) and Chandani *et al*. (2015) while not in agreement with Gogoi and Dutta (2000) who concluded that the relative humidity favors the jassid population. Rainfall also showed a non-significant and positive correlation with the jassid population (Riaz *et al*., 1987; Bashir *et al*., 2001). These results are not in agreement with our findings. While, Panwar *et al*. (2014) reported negative and significant affect of rainfall and wind velocity, which was partially same with our results.

On local varieties like the USDA accessions, low %R.H. and rainfall significantly increased jassid population as %R.H was significantly high and negative while, rainfall significantly negatively correlated with jassid population development (Tables II and III). Maximum temperature was important in the development of jassid population as compared to minimum as both were positive but maximum temperature was significantly affecting the jassid while, wind velocity was significantly high and positive.

Climatic conditions largely influence the incidence and development of whitefly (Chaudhari *et al*., 1999; Arif *et al*., 2006). It is necessary to sort out the exact nature / degree of relationship, which exists between whitefly population and weather factors, with ultimate aim to help the entomologist to develop the best integrated pest management strategy for the control of whitefly (Umar *et al*., 2003).

Same population development pattern of whitefly was recorded on USDA accessions and local varieties throughout the study period at 30, 60, 90 and 120 DAP. However, high infestation was recorded on local varieties as compared to USDA accessions. The most critical period for local varieties as well as USDA accessions was 90 DAP (Fig. 2). DAP was recorded positive, non-significantly correlated with USDA accessions while, in case of local varieties it was negative and non-significant (Tables I and II). This clearly indicated that whitefly attraction was more to USDA accessions as compared to the local varieties.

Because of low population pressure of thrips, whitefly population was not affected with increasing or decreasing trend of thrips on all the testing strains. Disease index was increased with whitefly population on both USDA and local varieties. It meant that highest population of whitefly could increase disease (%) and severity level.

As far as the abiotic factors were concerned with whitefly, highest % R.H. was increased significantly increased the whitefly population on USDA accessions whereas, it had positive non-significant effect on local varieties. Maximum temperature and high wind velocity non-significantly decreased while, minimum temperature and high rainfall were non-significantly increased the whitefly population on USDA accessions. Whereas, maximum and minimum temperatures, high %R.H, rainfall and wind velocity increased whitefly population on local varieties.

Seif (1980) and Gupta *et al*. (1998) reported that with increase in temperature and relative humidity, population of whitefly also increased. These findings are in favor of local varieties but in case of USDA accessions, it was partially in favor as we found negative correlation with maximum temperature. Rote and Puri (1991) reported that maximum temperature was positively correlated and %R.H was negative with the population of whitefly. Maximum temperature was in agreement in case of local varieties while, findings regarding the %R.H was not in agreement with all the varieties. The present findings about the rainfall on all the testing varieties in conformity with the results, demonstrated by Jalal *et al*. (2006) that whitefly population was positively correlated with the rainfall. Bashir *et al*. (2001) concluded that rainfall negatively correlated with whitefly population, however, disfavor with our studies. Selvaraj and Ramesh (2012) revealed that wind velocity was positively affect the whitefly population which was contradictory with our results as compared to USDA accessions however, it favored with local varieties while, Shitole and Patel (2009) reported the correlation of whitefly population was non-significant and negative association with wind velocity.

In early season cotton, thrips cause significant leaf area destruction, delayed maturity and retarded plant growth (Sadras and Wilson, 1998). Thrips is the sucking insect pest in cotton growing areas of Sindh and Punjab in Pakistan, along with Jassid and whitefly. Since its attack on lower side of cotton, leaves start with beginning of growth of cotton, so farmers are advised to be vigilant as attack’s severity increases in dry weather (Saleem *et al*., 2013).

Different population trend of thrips was recorded on USDA accessions as compared to local varieties on 30, 60, 90 and 120 DAP (Fig. 1). Local varieties were found most susceptible as compared to USDA accessions although, its population remained below ETL throughout the season.

Thrips were avoided infestation on all testing varieties when crop was going to maturity as DAP negatively and non-significantly correlated on all the varieties (Tables I and II). According to Fig. 5 thrips mostly preferred local varieties at 30 DAP (June-July) and 60 DAP (July-August). The present findings are in conformity with Saleem *et al.* (2013) who recorded data at different times of the season showed that thrips had a peak at in August and this month seems the most favorable period for the development of the pest, where Sewify *et al.* (1996) who reported that maximum population densities of sucking insect pests occurred during July, August and September and Gupta *et al.* (1997) observed that the highest population of thrips during the last week of July to mid August.

Thrips was shown same behavior like jassid regarding the disease index. Disease index was negative and non-significantly correlated on USDA while, it was positively with local varieties. It indicated that native thrips preferred native germplasms as USDA accessions were new for the abundance to native thrips. Increase of all abiotic factors were favored thrips population on all testing varieties except high %R.H reduced population on local varieties as it was found negatively correlated while, maximum and minimum temperatures significantly favored thrips population on local varieties.

Our finding regarding the %R.H is same with Saleem *et al.* (2013) in case of USDA accessions who reported that relative humidity positively affects thrips population while, (Khan *et al.*, 2008; Patel *et al.*, 2013) reported that %R.H had negative impacts in the development of thrips population which is in favor with local varieties. The effect of temperature was also significant and positive on thrips population (Arif *et al.*, 2006; Patel *et al.*, 2013). The present findings are in consonance typically with local varieties however, USDA accessions were found positive but non-significant correlation with temperature. According to Patel *et al.* (2013) rainfall had negative impact on thrips population while, we recorded positively correlation on both USDA accessions and local varieties.

Screened resistant and susceptible accessions of USDA and local varieties against CLCuV disease

Overwintering, viruliferous whitefly adults may thus inoculate cotton at various times during the growing season (Butler and Henneberry, 1984). Heavy abundance of whitefly was reported on all varieties at 90 DAP (Fig. 4). The most resistant accessions were USG-14-2464 and USG-14-2478. These recorded completely pest free and not shown any signs and symptoms of CLCuV disease at 60, 90 and 120 DAP (Table IV) although, low infestation level of whitefly/leaf was recorded 2.70, 2.80, 8.40 and 0.00 at 30, 60, 90 and 120 DAP, respectively on USG-14-2464 and 0.30, 4.00, 8.40 and 0.00 at 30, 60, 90 and 120 DAP respectively on USG-14-2478 (Fig. 4). USG-14-2484 and USG-14-2481 were competed against CLCuV disease as USG-14-2484 showed 5.60% (4.70 whitefly/ leaf), 8.80% (10.0 whitefly/leaf) and 9.10% (0.0 whitefly/ leaf) CLCuV disease with three severity level at 60, 90 and 120 DAP whereas, USG-14-2481 showed 25% (4.20 whitefly/ leaf), 35% (28.90 whitefly/leaf) and 50% (0.0 whitefly/ leaf) CLCuV disease with four severity level, respectively, at 60, 90 and 120 DAP (Table IV). The most susceptible accessions of USDA were USG-12-108, USG-14-2463 and USG-14-2486 on the basis of low infestation level of whitefly/leaf as (0.00) was on USG-12-108 and (0.20) both on USG-14-2463 and USG-14-2484 at 30 DAP recorded while, these accessions were shown 100% CLCuV disease with four severity levels at 60 DAP.

Correlation between disease index and abiotic factors on USDA accessions verses local varieties at 60, 90 and 120 DAP

Disease index increased with increased in DAP and infestation level of whitefly as it was positive and non-significantly correlated with DAP and whitefly on USDA accessions and local varieties (Tables II and III). The best example of correlation of disease index and DAP was USG-14-81 which showed 25% disease with three severity level and 15.60 disease index at 60 DAP while, 35.0% disease with four severity level and 37.50% disease index respectively at 90 DAP and 50.0% disease with four severity level and 43.70 disease index respectively at 120 DAP. Severity level and disease index could be decreased with better management practices especially the cultural practices.

Increased in maximum and minimum temperatures, rainfall and wind velocity were affected disease index as these were non-significantly positive correlated while, %R.H non-significantly increased disease index on both USDA accessions and local varieties (Tables II and III).

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Statement of conflict of interest

Authors have declared no conflict of interest.

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