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# Seasonal population trend and relative occurrence of pests and their natural enemies among cotton species and cultivars in India

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## Abstract

**Background** Cotton crop is infested by numerous arthropod pests from sowing to harvesting, causing substantial direct and indirect yield losses. Knowledge of seasonal population trends and the relative occurrence of pests and their natural enemies is required to minimize the pest population and yield losses. In the current study, analysis of the seasonal population trend of pests and natural enemies and their relative occurrence on cultivars of three cotton species in Central India has been carried out.

**Results** A higher number and diversity of sucking pests were observed during the vegetative cotton growth stage (60 days after sowing), declining as the crop matured. With the exception of cotton jassid (*Amrasca biguttula biguttula* Ishida), which caused significant crop damage mainly from August to September; populations of other sucking insects seldom reached economic threshold levels (ETL) throughout the studied period. The bollworm complex populations were minimal, except for the pink bollworm (*Pectinophora gossypiella* Saunders), which re-emerged as a menace to cotton crops during the cotton cropping season 2017–2018 due to resistance development against Bt-cotton. A reasonably good number of predatory arthropods, including coccinellids, lacewings, and spiders, were found actively preying on the arthropod pest complex of the cotton crop during the early vegetative growth stage. Linear regression indicates a significant relationship between green boll infestations and pink bollworm moths in pheromone traps. Multiple linear regression analyse showed mean weekly weather at one- or two-week lag periods had a significant impact on sucking pest population (cotton aphid, cotton jassid, cotton whitefly, and onion thrips) fluctuation. *Gossypium hirsutum* cultivars RCH 2 and DCH 32, and *G. barbadense* cultivar Suvin were found susceptible to cotton jassid and onion thrips. Phule Dhanvantary, an *G. arboreum* cotton cultivar, demonstrated the highest tolerance among all evaluated cultivars against all sucking pests.

**Conclusion** These findings have important implications for pest management in cotton crops. Susceptible cultivars warrant more attention for plant protection measures, making them more input-intensive. The choice of appropriate cultivars can help minimize input costs, thereby increasing net returns for cotton farmers.

**Keywords** Cotton, Pests, Population trend, Relative occurrence, Cultivars, Natural enemies

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## Background

India occupies the largest area of about 13 million ha under cotton cultivation with an annual production of 36 million bales. India is the only country growing all four species of cultivated cotton, viz., *Gossypium hirsutum* L. (upland cotton), *G. arboretum* (Asian cotton), *G.*

*herbaceum* L. (levant cotton), and *G. barbadense* L. (sea island cotton). Globally, *G. hirsutum* is the most widely planted cotton species, contributing > 90% of world fiber production followed by *G. barbadense* (accounting for 3% – 4%), *G. arboreum* (accounting for 2%), and *G. herbaceum* (accounting for 2%). *G. hirsutum* is native to Central America, *G. barbadense* to tropical South America, *G. arboreum* to India and Pakistan while *G. herbaceum* to southern Africa and the Arabian Peninsula. In India, *G. hirsutum* represents more than 95% of the total cotton area and production. Currently, genetically-modified cotton (Bt-cotton) accounts for more than 95% of the total cultivated area.

In India, 251 arthropod pests have been reported infesting cotton crops right from the seedling stage to the harvesting (Nagrare et al. 2022). These arthropod pests reduce potential yield in terms of quality as well as quantity to an extent from 50% to 60% depending upon the degree of infestation and stage of the crop (Sharma et al. 2017). Out of the total reported pests in India, 12 species are considered major pests that cause economic damage significantly for which growers have to take necessary control measures. The occurrence of insect pests depends upon geographical location, climate under which the crop is grown, previous crop grown, type of cultivar, agronomic practices, and so on. Understanding seasonal trends in pest and natural enemy populations is crucial for timely plant protection measures and preventing crop losses. In addition, the relative prevalence of pests among different cotton species is a key determinant of their pest tolerance. Cotton is being grown in three distinct zones of India, including the North, Central, and South zones, which have different agro-ecological and different sowing dates. In the North zone, cotton is sown in the month of April and May; in the Central zone, it is sown in June and July; and in the South zone, sowing occurs between June and September. Thus, the occurrence of insect pests and concurrent natural enemies has been distinct in these cotton cultivation zones. In all three zones common insect pests that cause significant injury are 'bollworms', namely cotton bollworm (*Helicoverpa armigera* Hubner), spotted bollworm (*Earias vittella* Fabricius), and pink bollworm (*Pectinophora gossypiella* Saunders); sucking pests as cotton aphid (*Aphis gossypii* Glover), cotton jassid (*Amrasca biguttula biguttula* Ishida), cotton whitefly (*Bemesia tabaci* Gennadius), onion thrips (*Thrips tabaci* Lindeman), and cotton mealybug (*Phenacocus solenopsis* Tinsley). Mirid bug (*Creanteadus biseretense* Distant), papaya mealybug (*Paracoccus marginatus* Williams de Ganara), tobacco caterpillar (*Spodoptera litura* Fabricius), and stem weevil (*Pempherulus affinis* Faust) are mostly prevalent in the South zone (Nagrare et al. 2022). These pests are reported to cause significant damage if timely control measures are not taken. Widespread infestation of *P. solenopsis* was recorded during 2007–2009 across India (Nagrare et al. 2009), but subsequently found in traces in most parts of the country.

Since the introduction of Bt-cotton in India in 2002, the area cultivated with *G. hirsutum* has increased substantially. Due to changes in genotypes and pest management strategies along with a reduction in insecticides for bollworm control, the dominance of sucking pests has been seen to a greater extent. In the last 8–9 years, a widespread infestation of pink bollworms on Bt-cotton added to the worry of cotton growers in all three zones of India (Naik et al. 2018; Fand et al. 2019a; Kumar et al. 2020). Currently, most of the cultivars are susceptible to the pink bollworm and sucking pests, which increased the cost of pest control. The majority of the cotton growers rely on sprays of synthetic insecticides to control pest infestation, which leads to resistance development against various insecticides, ecological contamination, and imbalance between biotic fauna in agro-ecosystems (Pathak et al. 2022). The present study analyzed the seasonal population trend of pests and natural enemies, and their relative occurrence on cultivars of three species of cotton across diverse agro-ecologies in Central India. The study aimed to test the hypothesis concerning the existence of significant variations in the seasonal population trend of pests within a season and over the years. Additionally, the relative occurrence of pests would differ significantly among the cultivars. The investigation will explore potential differences or patterns in the population trend of pests and the relative occurrence of their natural enemies across the cultivars of cotton, encompassing three distinct species.

## Materials and methods

### Experimental site and cultivars, design and agronomic practices

Data on the seasonal occurrence of cotton pests and natural enemies were collected from 2009 to 2019 (11 years) at experimental fields of Indian Council of Agricultural Research–Central Institute for Cotton Research (ICAR–CICR), Nagpur (21°12′19.25" N, 79°3′34.60" E) located in Central India. The data were gathered from cotton hybrid DCH32, planted in a 300 $m^2$ area every year at spacing $60 \times 60$ cm (row to row $\times$ plant to plant distance) under rainfed conditions and free from insecticide exposure.

The experiments exclusively on the relative occurrence of pests and their natural enemies were conducted for three consecutive years from 2016, 2017, and 2018 during the local cotton growing seasons at ICAR–CICR Nagpur. Five commonly grown cultivars of three major cultivated species of cotton were selected: *Gossypium hirsutum*

L. (Cv. Suraj), *G. arboreum* L. (Cv. Phule Dhanvantary), *G. barbadense* L. (Cv. Suvin) and their hybrids *G. hirsutum* × *G. barbadense* (Cv. RCH 2), *G. hirsutum* × *G. barbadense* (Cv. DCH 32). Cotton plants were sown at spacing 60 × 60 cm (row to row × plant to plant distance) under rainfed conditions. The experiments were conducted in a split plot design. The size of each plot was 10 × 10 m. All the treatments were split into protected and unprotected plots and replicated thrice. In protected sub-treatments, plant protection measures were applied based on economic threshold levels (ETLs) (Nagrare et al. 2019) while unprotected sub-treatments were left unsprayed throughout the experimental duration. In the protected block, three insecticidal sprays (Neem formulation, Flonicamid, and Thiamethoxam) were applied between 60–90 days after sowing (DAS). All cultivars used for the experimentation were without insecticide treatment prior to sowing. All required agronomic practices were carried out to grow plants normally and also minimize the impact of weeds.

#### Population counts on bollworms and tobacco caterpillar

The density of bollworms viz. cotton bollworm, spotted bollworm, and tobacco caterpillar was observed on 25 randomly surveyed plants while pink bollworm infestation was recorded by destructive sampling of 20 green bolls per plot during 2009–2019 in the population trend experiment. Data on pheromone trap catches of male moths of cotton bollworm, spotted bollworm, pink bollworm, and tobacco caterpillar were recorded at weekly intervals. For this, two pheromone traps for each pest species were installed at 50 m apart. Trapped male moths were counted and discarded after every weekly count.

#### Population counts on sucking pests

Population counts on major sucking pests, namely aphid, cotton jassid (nymphs and adults), cotton whitefly (adults), and onion thrips (nymphs and adults) were taken from 3 leaves (top, middle, and bottom) per plant from random 25 plants at weekly interval starting from July to January during each cropping season. For counting the density of sucking insect pests, the leaf was softly held at the petiole between the thumb and forefinger and turned gently so that the entire underside of the leaf was observable. The density of mirid (*Campylomma livida* Reuter) was counted from a top one-third portion of the plant (Nagrare et al. 2016). Two yellow sticky traps (placed 50 m apart in a 300 $m^2$ area) were also installed to record the population trend of cotton jassid and cotton whitefly. The population counts were recorded from 2009 to 2019 in the population trend experiment from 2016 to 2019 in the relative occurrence experiment.

#### Population count of natural enemies

In a cotton ecosystem, the most visible natural enemies are generalist predators like coccinellids (*Cheilomenes sexmaculata* Fabricius), lacewings (*Chrysoperla zastrowi silemii* Esben-Petersen), and spiders (*Neoscona theisi* Walckenaer). Their counts were taken as numbers present on the whole plant. Fifteen species of spider were reported, among them the most prominent spider was *Neoscona theisi* (Nagrare et al. 2015). Population counts were documented between 2009 and 2019 for the population trend experiment and between 2016 and 2019 for the relative occurrence experiment.

#### Statistical analysis

Using functions inbuilt in Microsoft Office Excel (ver. 2010), the data on the population trend of insect pests and natural enemies from the cotton ecosystem were averaged at weekly and yearly interval and plotted against corresponding standard meteorological week (SMW) to find out seasonal population trend (Shera et al. 2013). The mean seasonal and annual population was calculated using the following formula:

$$\text{Mean}(X) = \frac{\Sigma x}{N} \tag{1}$$

where $\Sigma x$ represents sum of all observations or data points and $N$ represents the total sample size or the number of data points. While data generated on the relative occurrence of pests and natural enemies on cultivars of three species of cotton pooled over three years (2016–2018) and square root transformed were analyzed using IBM SPSS statistical package.

#### Relationship between moth catches in pheromone traps and field symptoms of pink bollworm damage

The relationship between the mean moth trap catches and field damage of pink bollworm damage recorded during 2009–2019 was established using a linear regression equation given below (Fand et al. 2021; Fand 2021).

$$y = a + bx \tag{2}$$

where, $y$ is the field infestation of pink bollworm in terms of green boll damage (%), $x$ is the moth trap catches in sex pheromone traps two weeks prior to the appearance of field damage, $a$ is the intercept and $b$ is the slope of regression equation.

### Pest-weather relationship

We ese a multiple linear regression equation to evaluate the pest-weather relationship. The relationship was established between the weekly mean populations of sucking pests and corresponding climatic variables – temperature and relative humidity recorded at one or two weeks prior during 2009–2019 to determine the influence of seasonal weather on the trend of major sucking pests (cotton aphid, cotton jassid, cotton whitefly, and onion thrips) (Fand et al. 2019b).

$$y = a + b_1x_1 + b_2x_2 + b_3x_3 + b_4x_4 \tag{3}$$

where, $y$ is the mean weekly population per 3 leaves of sucking pests; $x_1$ is the maximum temperature ($T_{\max}$), $x_2$ is the minimum temperature ($T_{\min}$), $x_3$ is morning relative humidity ($RH_{\max}$), and $x_4$ is evening relative humidity ($RH_{\min}$), $a$ is the intercept and $b$ is the slope of the regression equation.

## Results

### Seasonal and annual population trend of bollworms and sucking pests

#### *Cotton bollworm*

From 2009 to 2019, the cotton bollworm was detected in traces and never surpassed the ETL of 10% infested squares or bolls. The onset of cotton bollworm larvae was observed from the 33$^{rd}$ SMW (13–19 August) and remained active until the 49$^{th}$ SMW (3–9 December). The maximum larval population was recorded at the 41$^{st}$ SMW (8–14 October) with 0.46 larvae per plant, and then decreased substantially.

Pheromone trap catches indicated negligible male moth captures (< 3 moths per trap in a week) until the 46$^{th}$ SMW (12–18 November), but thereafter, the number slightly increased at the 4$^{th}$ SMW (fourth week of January of next year) (Table 1). The larval population was comparatively higher during 2009–2010, 2010–2011, and 2011–2012 (ranging between 0.34–0.37 larvae per plant in a week). However, thereafter, the population was consistently below 0.10 larvae per plant in a week. Over the years, not more than 4 moths per trap in a week were trapped (Table 2).

#### *Spotted bollworm*

The spotted bollworm from 2009 to 2019 was recorded from the 37$^{th}$ SMW (10–16 September) and a maximum of 0.13 larvae per plant was recorded at the 50$^{th}$ SMW (10–16 December). Trap catches during the initial stage of crop growth (until the 37$^{th}$ SMW) were negligible, but thereafter, they started increasing, reaching a higher density during the 46$^{th}$ to the 1$^{st}$ SMW (third week of November to the first week of January of next year), with the highest number of male moth caught recorded at the 49$^{th}$ SMW (3–9 December) (11.54 moth catches per trap in a week) (Table 1). Similar to cotton bollworm, larval infestation of spotted bollworm was minimal and never surpassed the ETL of 10% infested squares or bolls during 2009–2019. Although moth catches for the consecutive three years (*i.e.* 2009–2010, 2010–2011, and 2011–2012) ranged between 9.05–13.30 moths per trap in a week, from 2012–2013 onwards, they remained consistently below 3 moths per trap in a week (Table 2).

#### *Pink bollworm*

Infestation of pink bollworm exceeded the ETL, with green boll infestation reaching ≥ 10%, commencing from the 39$^{th}$ SMW (24–30 September) and persisting throughout the season. The peak infestation period was recorded between the 49$^{th}$ and 4$^{th}$ SMW (the first week of December to the last week of January). During the initial cotton growing period (up to the 41$^{st}$ SMW), coinciding with vegetative growth, flowering, and squaring of the cotton, very low pheromone trap catches were recorded. However, trap catches exhibited an increasing trend as the season progressed. Maximum moth activity was observed from the 43$^{rd}$ SMW (22–28 October), towards the end of the season, aligning with the peak boll development period (Table 1). Pink bollworm larvae primarily feed on developing seeds of green bolls. The highest green boll infestation (56.86%) was observed in the 2017–2018 season. Pheromone trap data over the years displayed a zigzag trend. The highest moth catches (ranging from 15.21–18.81 moths per trap in a week) occurred in 2011–2012, 2013–2014, 2015–2016, and 2017–2018. However, in recent years (2018–2019 and 2019–2020), pheromone trap catches were consistently below 5 moths per trap in a week (Table 2). Linear regression analysis revealed a significant relationship between mean green boll infestation and male moth trap catches in sex pheromone traps, recorded approximately two weeks before the appearance of damage in the cotton field ($y = 6.69 + 1.04x$; $r^2 = 0.776\ 7$, $P < 0.001$, $F = 78.85$). The $r^2$ value indicates that 77.67% of the variability in the appearance of boll damage by pink bollworm is attributed to the corresponding value of male moth catches in sex pheromone traps obtained approximately two weeks before the appearance of field symptoms of pest damage.

#### *Tobacco caterpillar*

Infestation of tobacco caterpillar larvae on cotton plants over the 11 years of observations has been consistently absent except in 2011–2012 and 2014–2015 (0.01 and 0.11 larvae per plant, respectively). During the initial crop growth stage (31st–39th SMW), pheromone trap catches were substantial, ranging from 28.94 to 134.01 moths per trap in a week, but the corresponding infestation on the cotton crop was negligible. It is possible that the moths might have migrated from other field crops, such as soybeans. From the 40th to 4th SMW (1st October to 28 January of the next year), moth catches remained below 50 moths per trap in a week (Table 1). Despite recurrent moth catches in the pheromone traps over the years, this was not reflected in damage by larvae. The moth catches of tobacco caterpillar do not carry significance, even though a higher number of moths were trapped during 2009–2010 (180.18 moths per trap in a week), 2012–2013 (81.94 moths per trap in a week), and 2014–2015 (109.69 moths per trap in a week). On the contrary, trap catches remained between 6.14–28.52 moths per trap in a week during the rest of the years (Table 2).

### *Cotton aphid*

Infestation of cotton aphid on cotton plants was documented starting from the 30th SMW (last week of July), with higher infestation recorded during the vegetative stage, specifically at the 32nd SMW (6–12 August) with a count of 34.73 aphids per 3 leaves. Subsequently, the infestation remained at a low level (< 19 cotton aphids per 3 leaves) throughout the cropping season (Table 3). Analysis of cotton aphid population over the years revealed that, broadly, the cotton aphid population was under control (< 13 cotton aphids per 3 leaves), except for the 2013–2014 season when aphid counts reached 18.02 per 3 leaves (Table 4). A multiple linear regression was conducted between the mean weekly aphid

**Table 1** Seasonal population trend of bollworms and tobacco caterpillar in the cotton crop season

| SMW | Corresponding days of SMW | Cotton bollworm | | Spotted bollworm | | Pink bollworm | | Tobacco caterpillar | |
|---|---|---|---|---|---|---|---|---|---|
| | | No. of larvae per plant | Male moth catches per trap in a week | No. of larvae per plant | Male moth catches per trap in a week | Green bolls infestation /% | Male moth catches per trap in a week | No. of larvae per plant | Male moth catches per trap in a week |
| 30 | 23 Jul – 29 Jul | 0.00 ± 0.00 | 0.06 ± 0.04 | 0.00 ± 0.00 | 0.12 ± 0.09 | 0.00 ± 0.00 | 0.63 ± 0.23 | 0.00 ± 0.00 | 8.88 ± 2.79 |
| 31 | 30 Jul – 05 Aug | 0.00 ± 0.00 | 0.28 ± 0.16 | 0.00 ± 0.00 | 0.35 ± 0.18 | 0.00 ± 0.00 | 0.61 ± 0.20 | 0.00 ± 0.00 | 32.66 ± 23.88 |
| 32 | 06 Aug – 12 Aug | 0.00 ± 0.00 | 0.61 ± 0.29 | 0.00 ± 0.00 | 0.71 ± 0.26 | 0.00 ± 0.00 | 0.38 ± 0.13 | 0.00 ± 0.01 | 48.10 ± 43.14 |
| 33 | 13 Aug – 19 Aug | 0.01 ± 0.01 | 1.50 ± 1.36 | 0.00 ± 0.00 | 0.73 ± 0.32 | 0.00 ± 0.00 | 0.38 ± 0.15 | 0.02 ± 0.03 | 104.79 ± 68.75 |
| 34 | 20 Aug – 26 Aug | 0.03 ± 0.02 | 0.39 ± 0.17 | 0.00 ± 0.00 | 0.87 ± 0.46 | 0.00 ± 0.00 | 0.33 ± 0.12 | 0.00 ± 0.01 | 28.94 ± 15.17 |
| 35 | 27 Aug – 02 Sep | 0.10 ± 0.07 | 0.44 ± 0.26 | 0.00 ± 0.00 | 0.32 ± 0.12 | 2.50 ± 0.00 | 0.17 ± 0.08 | 0.01 ± 0.01 | 46.21 ± 33.85 |
| 36 | 03 Sep – 09 Sep | 0.10 ± 0.07 | 0.91 ± 0.36 | 0.00 ± 0.00 | 0.80 ± 0.26 | 5.00 ± 0.00 | 0.55 ± 0.16 | 0.00 ± 0.00 | 59.50 ± 36.44 |
| 37 | 10 Sep – 16 Sep | 0.24 ± 0.12 | 1.69 ± 0.57 | 0.02 ± 0.01 | 0.52 ± 0.21 | 0.00 ± 0.00 | 0.44 ± 0.14 | 0.13 ± 0.06 | 88.94 ± 76.45 |
| 38 | 17 Sep – 23 Sep | 0.26 ± 0.15 | 2.65 ± 1.51 | 0.00 ± 0.00 | 1.35 ± 0.55 | 3.50 ± 4.67 | 0.93 ± 0.24 | 0.00 ± 0.00 | 134.01 ± 70.69 |
| 39 | 24 Sep – 30 Sep | 0.26 ± 0.15 | 0.90 ± 0.30 | 0.00 ± 0.00 | 2.21 ± 0.84 | 14.00 ± 9.45 | 1.42 ± 0.51 | 0.01 ± 0.01 | 86.04 ± 60.02 |
| 40 | 01 Oct – 07 Oct | 0.29 ± 0.17 | 1.26 ± 0.41 | 0.00 ± 0.01 | 2.01 ± 1.03 | 14.67 ± 11.16 | 0.91 ± 0.50 | 0.00 ± 0.00 | 25.70 ± 9.09 |
| 41 | 08 Oct – 14 Oct | 0.46 ± 0.31 | 0.89 ± 0.29 | 0.02 ± 0.01 | 2.87 ± 2.11 | 19.40 ± 12.01 | 1.39 ± 0.79 | 0.00 ± 0.00 | 28.12 ± 6.50 |
| 42 | 15 Oct – 21 Oct | 0.21 ± 0.15 | 1.71 ± 0.65 | 0.01 ± 0.01 | 4.93 ± 2.04 | 15.00 ± 6.78 | 4.88 ± 2.14 | 0.00 ± 0.00 | 41.55 ± 11.05 |
| 43 | 22 Oct – 28 Oct | 0.12 ± 0.09 | 1.03 ± 0.41 | 0.03 ± 0.02 | 3.56 ± 1.49 | 14.09 ± 5.09 | 13.66 ± 8.61 | 0.00 ± 0.00 | 25.71 ± 4.19 |
| 44 | 29 Oct – 04 Nov | 0.14 ± 0.08 | 1.50 ± 0.47 | 0.02 ± 0.01 | 3.93 ± 1.32 | 10.67 ± 4.76 | 11.57 ± 4.74 | 0.00 ± 0.00 | 46.41 ± 13.15 |
| 45 | 05 Nov – 11 Nov | 0.02 ± 0.02 | 1.64 ± 0.41 | 0.00 ± 0.00 | 4.08 ± 2.13 | 17.72 ± 6.05 | 14.09 ± 8.66 | 0.00 ± 0.00 | 44.54 ± 13.56 |
| 46 | 12 Nov – 18 Nov | 0.05 ± 0.03 | 1.51 ± 0.58 | 0.02 ± 0.02 | 9.13 ± 5.00 | 22.00 ± 7.69 | 9.52 ± 2.09 | 0.00 ± 0.00 | 20.39 ± 4.09 |
| 47 | 19 Nov – 25 Nov | 0.05 ± 0.05 | 3.38 ± 0.72 | 0.03 ± 0.03 | 9.71 ± 5.40 | 24.16 ± 8.93 | 11.60 ± 2.59 | 0.00 ± 0.00 | 24.54 ± 9.64 |
| 48 | 26 Nov – 02 Dec | 0.00 ± 0.00 | 4.19 ± 1.50 | 0.03 ± 0.03 | 6.82 ± 3.25 | 21.00 ± 6.62 | 26.35 ± 8.71 | 0.00 ± 0.00 | 19.67 ± 5.25 |
| 49 | 03 Dec – 09 Dec | 0.15 ± 0.15 | 6.98 ± 2.32 | 0.10 ± 0.05 | 11.54 ± 7.65 | 36.19 ± 9.42 | 23.86 ± 7.19 | 0.00 ± 0.00 | 16.23 ± 4.54 |
| 50 | 10 Dec – 16 Dec | 0.02 ± 0.02 | 5.48 ± 1.86 | 0.13 ± 0.09 | 8.80 ± 5.99 | 34.00 ± 9.68 | 22.16 ± 5.74 | 0.00 ± 0.00 | 12.97 ± 4.31 |
| 51 | 17 Dec – 23 Dec | 0.02 ± 0.02 | 5.44 ± 3.12 | 0.04 ± 0.05 | 7.97 ± 5.34 | 29.30 ± 13.77 | 31.35 ± 11.49 | 0.00 ± 0.00 | 18.63 ± 8.15 |
| 52 | 24 Dec – 31 Dec | 0.04 ± 0.04 | 4.61 ± 2.01 | 0.08 ± 0.07 | 3.60 ± 1.86 | 36.69 ± 1.89 | 25.75 ± 6.37 | 0.00 ± 0.00 | 10.52 ± 2.90 |
| 1 | 01 Jan – 07 Jan | 0.04 ± 0.04 | 8.13 ± 3.82 | 0.10 ± 0.08 | 7.91 ± 5.00 | 21.25 ± 0.72 | 21.92 ± 8.03 | 0.00 ± 0.00 | 18.02 ± 9.46 |
| 2 | 08 Jan – 14 Jan | 0.13 ± 0.09 | 5.11 ± 3.65 | 0.06 ± 0.06 | 0.67 ± 0.67 | 30.00 ± 3.82 | 17.96 ± 16.24 | 0.00 ± 0.00 | 7.17 ± 6.33 |
| 3 | 15 Jan – 21 Jan | 0.00 ± 0.00 | 4.72 ± 3.28 | – | 0.75 ± 0.25 | 37.08 ± 18.82 | 32.59 ± 27.44 | 0.00 ± 0.00 | 9.86 ± 9.14 |
| 4 | 22 Jan – 28 Jan | 0.00 ± 0.00 | 10.38 ± 5.22 | – | 1.83 ± 1.09 | 43.75 ± 2.60 | 38.05 ± 31.63 | 0.00 ± 0.00 | 22.98 ± 12.00 |

*SMW* standard meteorological week. "–" represent infestation of spotted bollworm in green bolls was not seen during 3 and 4 SMW. Data represent mean ± standard error

**Table 2** Annual mean population of bollworms and tobacco caterpillar over the years 2009–2019

| Year | Cotton bollworm | | Spotted bollworm | | Pink bollworm | | Tobacco caterpillar | |
|---|---|---|---|---|---|---|---|---|
| | No. of larvae per plant | Male moth catches per trap in a week | No. of larvae per plant | Male moth catches per trap in a week | Green bolls infestation /% | Male moth catches per trap in a week | No. of larvae per pant | Male moth catches per trap in a week |
| 2009–2010 | 0.36 ± 0.09 | 3.45 ± 1.23 | 0.13 ± 0.02 | 9.05 ± 3.25 | – | 0.45 ± 0.18 | 0.00 ± 0.00 | 180.18 ± 44.70 |
| 2010–2011 | 0.34 ± 0.11 | 3.25 ± 1.52 | 0.00 ± 0.00 | 13.30 ± 3.84 | – | 6.48 ± 2.14 | 0.00 ± 0.00 | 28.52 ± 3.89 |
| 2011–2012 | 0.37 ± 0.16 | 0.32 ± 0.10 | 0.00 ± 0.00 | 9.05 ± 3.25 | 1.45 ± 0.73 | 15.21 ± 6.25 | 0.01 ± 0.01 | 9.77 ± 2.58 |
| 2012–2013 | 0.05 ± 0.05 | 1.21 ± 0.38 | 0.00 ± 0.00 | 1.19 ± 0.24 | 8.00 ± 2.83 | 10.23 ± 4.02 | 0.00 ± 0.01 | 81.94 ± 22.36 |
| 2013–2014 | 0.03 ± 0.01 | 2.56 ± 0.76 | 0.00 ± 0.00 | 0.80 ± 0.14 | 23.46 ± 4.01 | 18.81 ± 6.29 | 0.00 ± 0.00 | 25.07 ± 4.64 |
| 2014–2015 | 0.00 ± 0.00 | 2.24 ± 0.67 | 0.00 ± 0.00 | 1.10 ± 0.34 | 15.38 ± 3.64 | 4.17 ± 1.52 | 0.11 ± 0.05 | 109.69 ± 60.01 |
| 2015–2016 | 0.00 ± 0.00 | 2.78 ± 0.68 | 0.00 ± 0.00 | 2.72 ± 0.88 | 18.27 ± 2.50 | 15.66 ± 5.95 | 0.00 ± 0.01 | 16.80 ± 2.76 |
| 2016–2017 | 0.00 ± 0.00 | 3.23 ± 1.10 | 0.00 ± 0.00 | 2.36 ± 0.60 | 8.32 ± 2.37 | 7.70 ± 2.13 | 0.00 ± 0.00 | 23.11 ± 4.92 |
| 2017–2018 | 0.03 ± 0.02 | 1.47 ± 0.31 | 0.01 ± 0.01 | 1.72 ± 0.30 | 55.86 ± 5.77 | 15.77 ± 5.78 | 0.00 ± 0.00 | 9.26 ± 1.23 |
| 2018–2019 | 0.04 ± 0.02 | 1.65 ± 0.40 | 0.00 ± 0.00 | 0.32 ± 0.09 | 18.13 ± 3.89 | 2.32 ± 0.44 | 0.00 ± 0.00 | 6.14 ± 1.57 |
| 2019–2020 | 0.00 ± 0.00 | 1.38 ± 0.28 | 0.00 ± 0.00 | 0.97 ± 0.25 | 17.63 ± 4.29 | 4.58 ± 1.42 | 0.00 ± 0.00 | 20.43 ± 2.15 |

"–" represent infestation of pink bollworm in green bolls was not seen during 2009–2010 and 2010–2011. Data represent mean ± standard error

population and the mean weekly values of weather factors recorded two weeks before the pest population, and it was found to be statistically significant (Table 5). The established relationship is: cotton aphid population per 3 leaves = 115.60–2.82×$T_{max}$+1.85×$T_{min}$– 0.72×$RH_{max}$. The $T_{max}$ of the day and $RH_{min}$ exerted a significant negative influence, whereas the $T_{min}$ had a significant positive influence on the buildup of aphid populations.

### *Cotton jassid*

Infestation of cotton jassid commenced during the seedling stage of the crop and persisted throughout the crop season, with higher activities observed between the 32$^{nd}$ to 38$^{th}$ SMW (the second week of August to the third week of September) at levels of 7.87–11.36 cotton jassid per 3 leaves, exceeding the ETL (above 6 cotton jassid per 3 leaves) when the crop was in the vegetative stage. The peak infestation occurred at the 36$^{th}$ SMW (3–9 September) with 11.36 cotton jassid per 3 leaves. Data from yellow sticky traps revealed the highest cotton jassid trapped between the 37$^{th}$ to 50$^{th}$ SMW (mid-September to the first week of November), ranging from 390.00 to 727.75 cotton jassid per trap in a week. The peak trap catches were observed at the 43$^{rd}$ SMW (22–28 October) with 727.75 cotton jassid per trap in a week, followed by the 45$^{th}$ SMW (the second week of November) with 642.38 cotton jassid per trap in a week (Table 3). Among the years of observation, cotton jassid infestation was the highest during 2009–2010 (8.61 cotton jassid per 3 leaves), followed by 2010–2011 (7.81 cotton jassid per 3 leaves) and 2017–2018 (6.51 cotton jassid per 3 leaves). Conversely, during 2011–2012, 2012–2013, 2015–2016, and 2019–2020, cotton jassid infestation was below 5 cotton jassid per 3 leaves. Comparing among the years, the maximum cotton jassid population was recorded during 2014–2015 (833.36 cotton jassid per trap in a week), followed by 2016–2017 (821.50 cotton jassid per trap in a week) and 2013–2014 (812.09 cotton jassid per trap in a week). Lower cotton jassid trap catches occurred during 2015–2016, 2017–2018, and 2019–2020 ($<$ 315 cotton jassid per trap in a week) (Table 4). A multiple linear regression fitted between the mean weekly jassid population and the mean weekly values of climatic variables recorded one week before the pest population was found to be significant (Table 6). The established relationship is provided: cotton jassid population per 3 leaves = –21.92+0.63×$T_{max}$–0.56×$T_{min}$+0.33×$RH_{min}$. The $T_{max}$ of the day and $RH_{min}$ had a significant positive influence, whereas the $T_{min}$ had a significant negative influence on the population buildup of cotton jassid.

### *Cotton whitefly*

Infestation of cotton whitefly remained consistently below 3 cotton whitefly per 3 leaves throughout the entire period of observation and across all years, significantly below the ETL of 18 cotton whitefly per 3 leaves. Yellow sticky trap catches indicated maximum adult captures between the 37$^{th}$ and 45$^{th}$ SMW (the second week of September to the second week of November), with the highest recorded at the 43$^{rd}$ SMW (the fourth week of October) at 223.92 cotton whitefly per trap in a week, followed by the 42nd SMW (the third week of October) at 172.57 cotton whitefly per trap in a week (Table 3). The yearly trend of yellow sticky trap catch data revealed the highest population recorded during 2018–2019 (303.27 cotton whitefly per trap in a week),

**Table 3** Seasonal population trend of sucking pests in the cotton crop season

| SMW | Corresponding days of SMW | Cotton aphid per 3 leaves | Cotton jassid per 3 leaves | Cotton jassid catches per yellow sticky trap in a week | Cotton whitefly per 3 leaves | Cotton whitefly catches per yellow sticky trap in a week | Onion thrips per 3 leaves | Mirid bug per top one-third portion |
|---|---|---|---|---|---|---|---|---|
| 30 | 23 Jul – 29 Jul | 3.97 ± 2.85 | 4.42 ± 2.36 | – | 0.65 ± 0.32 | – | 2.47 ± 1.00 | 0.10 ± 0.02 |
| 31 | 30 Jul – 05 Aug | 11.00 ± 5.87 | 5.45 ± 2.13 | – | 0.68 ± 0.37 | – | 1.40 ± 0.41 | 0.10 ± 0.06 |
| 32 | 06 Aug – 12 Aug | 34.73 ± 6.57 | 9.22 ± 3.14 | 140.50 ± 72.00 | 1.71 ± 0.42 | 41.50 ± 1.00 | 3.47 ± 0.80 | 0.15 ± 0.08 |
| 33 | 13 Aug – 19 Aug | 18.47 ± 4.62 | 9.79 ± 3.41 | 454.00 ± 169.85 | 1.47 ± 0.20 | 56.83 ± 9.53 | 3.48 ± 1.01 | 0.24 ± 0.10 |
| 34 | 20 Aug – 26 Aug | 11.39 ± 4.17 | 9.55 ± 3.30 | 441.63 ± 128.44 | 1.81 ± 0.30 | 84.88 ± 37.18 | 5.19 ± 0.97 | 0.22 ± 0.11 |
| 35 | 27 Aug – 02 Sep | 9.38 ± 4.04 | 7.88 ± 1.28 | 354.88 ± 39.25 | 2.54 ± 0.58 | 118.00 ± 13.00 | 4.31 ± 1.58 | 0.15 ± 0.05 |
| 36 | 03 Sep – 09 Sep | 12.02 ± 5.29 | 11.36 ± 1.44 | 350.50 ± 65.67 | 2.35 ± 0.37 | 119.83 ± 27.28 | 3.49 ± 1.30 | 0.27 ± 0.07 |
| 37 | 10 Sep – 16 Sep | 7.88 ± 3.48 | 9.65 ± 2.46 | 538.33 ± 129.08 | 1.93 ± 0.47 | 166.71 ± 45.21 | 3.08 ± 1.42 | 0.37 ± 0.08 |
| 38 | 17 Sep – 23 Sep | 11.24 ± 4.26 | 7.87 ± 1.29 | 390.00 ± 103.20 | 2.12 ± 0.40 | 129.43 ± 44.38 | 1.91 ± 0.43 | 0.57 ± 0.21 |
| 39 | 24 Sep – 30 Sep | 3.86 ± 1.29 | 5.78 ± 0.98 | 601.25 ± 182.59 | 1.84 ± 0.53 | 116.93 ± 43.77 | 1.53 ± 0.42 | 0.59 ± 0.29 |
| 40 | 01 Oct – 07 Oct | 6.57 ± 3.63 | 5.06 ± 0.85 | 477.50 ± 100.82 | 1.89 ± 0.43 | 129.18 ± 48.49 | 1.96 ± 1.01 | 0.60 ± 0.20 |
| 41 | 08 Oct – 14 Oct | 2.97 ± 1.28 | 4.90 ± 1.01 | 589.93 ± 181.69 | 1.32 ± 0.24 | 149.82 ± 57.09 | 1.61 ± 0.73 | 0.62 ± 0.24 |
| 42 | 15 Oct – 21 Oct | 3.88 ± 1.39 | 3.93 ± 0.54 | 589.96 ± 190.49 | 1.49 ± 0.40 | 172.57 ± 76.17 | 1.88 ± 0.72 | 0.52 ± 0.27 |
| 43 | 22 Oct – 28 Oct | 3.92 ± 1.26 | 3.42 ± 0.73 | 727.75 ± 155.08 | 1.51 ± 0.26 | 223.92 ± 82.52 | 1.09 ± 0.33 | 0.50 ± 0.20 |
| 44 | 29 Oct – 04 Nov | 3.08 ± 0.91 | 2.94 ± 0.46 | 585.71 ± 173.42 | 1.40 ± 0.18 | 139.04 ± 37.83 | 1.28 ± 0.39 | 0.39 ± 0.11 |
| 45 | 05 Nov – 11 Nov | 5.01 ± 1.80 | 3.24 ± 0.86 | 642.38 ± 245.97 | 0.90 ± 0.16 | 148.31 ± 28.87 | 1.37 ± 0.48 | 0.28 ± 0.07 |
| 46 | 12 Nov – 18 Nov | 4.54 ± 2.85 | 2.70 ± 0.68 | 510.75 ± 213.57 | 1.09 ± 0.23 | 52.42 ± 26.07 | 1.47 ± 0.54 | 0.30 ± 0.08 |
| 47 | 19 Nov – 25 Nov | 3.89 ± 2.12 | 2.90 ± 0.62 | 476.50 ± 176.41 | 1.18 ± 0.33 | 85.58 ± 23.24 | 1.10 ± 0.42 | 0.24 ± 0.08 |
| 48 | 26 Nov – 02 Dec | 5.36 ± 2.87 | 2.82 ± 1.07 | 490.75 ± 284.02 | 1.15 ± 0.44 | 144.33 ± 27.03 | 0.44 ± 0.18 | 0.26 ± 0.15 |
| 49 | 03 Dec – 09 Dec | 3.94 ± 2.86 | 2.28 ± 1.13 | 596.33 ± 245.71 | 1.04 ± 0.25 | 101.65 ± 7.24 | 0.45 ± 0.16 | 0.33 ± 0.33 |
| 50 | 10 Dec – 16 Dec | 2.43 ± 0.63 | 2.18 ± 0.80 | 546.50 ± 357.00 | 1.29 ± 0.16 | 88.25 ± 14.25 | 1.34 ± 0.59 | 0.25 ± 0.25 |
| 51 | 17 Dec – 23 Dec | 5.00 ± 1.95 | 2.38 ± 0.44 | 400.75 ± 199.25 | 1.31 ± 0.08 | 82.50 ± 23.50 | 1.01 ± 0.40 | 0.30 ± 0.30 |
| 52 | 24 Dec – 31 Dec | 6.00 ± 2.40 | 2.81 ± 0.74 | 377.00 ± 113.00 | 1.41 ± 0.55 | 92.75 ± 1.25 | 2.65 ± 0.71 | 0.28 ± 0.36 |
| 1 | 01 Jan – 07 Jan | 5.80 ± 2.81 | 2.17 ± 0.35 | – | 1.16 ± 0.16 | – | 1.15 ± 0.37 | 0.20 ± 0.14 |
| 2 | 08 Jan – 14 Jan | 7.20 ± 4.50 | 3.21 ± 0.65 | – | 1.08 ± 0.30 | – | 2.29 ± 0.58 | – |
| 3 | 15 Jan – 21 Jan | 6.20 ± 3.10 | 3.47 ± 1.73 | – | 1.13 ± 0.49 | – | 1.47 ± 0.68 | – |
| 4 | 22 Jan – 28 Jan | 8.70 ± 4.35 | 1.33 ± 0.67 | – | 0.97 ± 0.43 | – | 0.63 ± 0.24 | – |

*SMW* standard meteorological week

"–" represent data collection with respect to yellow sticky trap catches of cotton jassid and cotton whitefly focused during August to December; mirid bug population remain less during fag end of season, thus could not record the data during 2 to 4 SMW. Data represent mean ± standard error

followed by 2017–2018 (147.32 cotton whitefly per trap in a week); however, this did not translate into a corresponding increase in plant infestation (Table 4). A multiple linear regression analysis was conducted between the mean weekly cotton whitefly population and the mean weekly values of weather factors recorded one week before the pest population, and it was found to be statistically significant (Table 7). The established relationship is: cotton whitefly population per 3 leaves = $-7.76 + 0.33 \times T_{max} - 0.22 \times T_{min} - 0.02 \times RH_{max} + 0.09 \times RH_{min}$. The $T_{max}$ of the day and $RH_{min}$ had a significant positive influence on the population buildup of cotton whitefly, whereas the $T_{min}$ and $RH_{max}$ had a significant negative influence, respectively.

#### *Onion thrips*

The activity of onion thrips commenced at the seedling stage and persisted until boll maturity. Despite that, the onion thrips population did not surpass the ETL of 30 onion thrips per 3 leaves. The density, however, was notably higher during the 32nd to 37th SMW (the second week of August to the third week of September) (Table 3). This period usually coincides with warm and dry weather conditions. Yearly observations indicated that the maximum onion thrips count (4.09 onion thrips per 3 leaves) occurred during 2011–2012, followed by 2014–2015 and 2018–2019 (Table 4). A multiple linear regression analysis was conducted between the mean weekly onion thrips population and the mean weekly values of weather factors recorded one week before the pest population, revealing statistical significance (Table 8). The

**Table 4** Annual mean population of sucking pests over the years 2009–2019

| Year | Cotton aphid per 3 leaves | Cotton jassid per 3 leaves | Cotton jassid catches per yellow sticky trap in a week | Cotton whitefly per 3 leaves | Cotton whitefly catches per yellow sticky trap in a week | Onion thrips per 3 leaves | Mirid bug per top one-third portion |
|---|---|---|---|---|---|---|---|
| 2009–2010 | 3.45 ± 1.23 | 8.61 ± 2.14 | – | 1.56 ± 0.19 | – | 1.46 ± 0.48 | 1.32 ± 0.23 |
| 2010–2011 | 4.36 ± 1.87 | 7.81 ± 1.47 | – | 1.66 ± 0.25 | – | 2.79 ± 0.33 | 0.40 ± 0.05 |
| 2011–2012 | 12.39 ± 2.92 | 2.27 ± 0.49 | – | 1.31 ± 0.25 | – | 4.09 ± 1.02 | 0.07 ± 0.06 |
| 2012–2013 | 9.62 ± 1.44 | 1.46 ± 0.15 | – | 2.40 ± 0.43 | – | 1.58 ± 0.57 | 0.76 ± 0.20 |
| 2013–2014 | 18.02 ± 3.81 | 6.27 ± 0.74 | 812.09 ± 52.85 | 1.38 ± 0.18 | 119.88 ± 14.41 | 1.23 ± 0.21 | 0.33 ± 0.05 |
| 2014–2015 | 5.11 ± 1.52 | 6.24 ± 1.40 | 833.36 ± 130.65 | 1.83 ± 0.48 | 66.29 ± 18.93 | 3.74 ± 1.71 | 0.33 ± 0.06 |
| 2015–2016 | 8.12 ± 2.69 | 3.83 ± 0.62 | 313.11 ± 45.08 | 1.00 ± 0.22 | 24.89 ± 8.93 | 1.35 ± 0.31 | 0.14 ± 0.03 |
| 2016–2017 | 1.86 ± 0.70 | 6.10 ± 1.08 | 821.50 ± 125.76 | 1.62 ± 0.40 | 41.21 ± 12.89 | 1.65 ± 0.69 | 0.09 ± 0.02 |
| 2017–2018 | 2.67 ± 0.93 | 6.51 ± 0.98 | 200.79 ± 29.92 | 1.92 ± 0.20 | 147.32 ± 20.53 | 2.18 ± 0.59 | 0.19 ± 0.05 |
| 2018–2019 | 11.01 ± 3.62 | 5.46 ± 0.66 | 635.18 ± 35.33 | 1.26 ± 0.20 | 303.27 ± 58.31 | 3.49 ± 0.77 | 0.19 ± 0.04 |
| 2019–2020 | 3.94 ± 0.46 | 3.62 ± 0.35 | 239.65 ± 25.84 | 1.19 ± 0.12 | 127.63 ± 11.26 | 1.81 ± 0.26 | 0.23 ± 0.04 |

"–" represent initiated yellow sticky data collection of cotton jassid and cotton whitefly starting from 2013–2014. Data represent mean ± standard error

**Table 5** Multiple linear regression between mean weekly cotton aphid population per 3 leaves and mean weekly values of weather factors at two weeks lag during cotton growing seasons from 2009 to 2019 at Nagpur, Maharashtra

| Parameters | Coefficients | Std. error | *t* test | *P* | $r^2$ | *df* | *F* | Sig. of *F* |
|---|---|---|---|---|---|---|---|---|
| Intercept | 115.60 | 27.72 | 4.17 | 0.000 4 | 0.70 | 3, 23 | 17.56 | 0.000 003 |
| $b_1$ ($T_{max}$) | − 2.82 | 0.49 | −5.75 | 0.000 0 | | | | |
| $b_2$ ($T_{min}$) | 1.85 | 0.43 | 4.33 | 0.000 2 | | | | |
| $b_3$ ($RH_{max}$) | − 0.72 | 0.31 | −2.33 | 0.028 7 | | | | |

**Table 6** Multiple linear regression between mean weekly cotton jassid population per 3 leaves and mean weekly values of weather factors at one week lag during cotton growing seasons from 2009 to 2019 at Nagpur, Maharashtra

| Parameters | Coefficients | Std. error | *t* test | *P* | $r^2$ | *df* | *F* | Sig. of *F* |
|---|---|---|---|---|---|---|---|---|
| Intercept | − 21.92 | 8.25 | −2.66 | 0.01 | 0.86 | 3, 22 | 44.56 | < 0.0001 |
| $b_1$ ($T_{max}$) | 0.63 | 0.29 | 2.13 | 0.04 | | | | |
| $b_2$ ($T_{min}$) | − 0.56 | 0.23 | −2.42 | 0.02 | | | | |
| $b_3$ ($RH_{min}$) | 0.33 | 0.07 | 4.78 | 0.00 | | | | |

**Table 7** Multiple linear regression between mean weekly cotton whitefly population per 3 leaves and mean weekly values of weather factors at one-week lag during cotton growing seasons from 2009 to 2019 at Nagpur, Maharashtra

| Parameters | Coefficients | Std. error | *t* test | *P* | $r^2$ | *df* | *F* | Sig. of *F* |
|---|---|---|---|---|---|---|---|---|
| Intercept | − 7.76 | 4.11 | −1.89 | 0.07 | 0.52 | 4, 21 | 5.69 | 0.003 |
| $b_1$ ($T_{max}$) | 0.33 | 0.10 | 3.16 | 0.005 | | | | |
| $b_2$ ($T_{min}$) | −0.22 | 0.09 | −2.60 | 0.02 | | | | |
| $b_3$ ($RH_{max}$) | − 0.02 | 0.05 | −0.36 | 0.72 | | | | |
| $b_4$ ($RH_{min}$) | 0.09 | 0.03 | 3.12 | 0.005 | | | | |

established relationship is provided below: onion thrips population per 3 leaves = $-2.38+0.38\times T_{max}-0.28\times T_{min}-0.17\times RH_{max}+0.21\times RH_{min}$. The $T_{max}$ of the day and $RH_{min}$ had a significant positive influence on the population buildup of onion thrips, whereas the $T_{min}$ and $RH_{max}$ had a significant negative influence, respectively.

#### *Mirid bug*

Mirid bug is a minor pest of cotton, mostly prevalent in the Central and South cotton-growing zones of India. The population of mirid bug begins to increase from the 38th SMW (the third week of September) onwards, coinciding with square and flower formation on the crop. However, their numbers were consistently found to be negligible (< 1 per one-third top portion of the plant) in the remaining parts of the season (Table 3). Throughout all the years, the population of mirid bug remained negligible in cotton crops. The yearly trends indicate that the maximum count of mirid bug was recorded during 2009–2010 (1.32 mirid bug per one-third top portion of the plant), but in subsequent years, the population decreased substantially (Table 4).

### Seasonal and annual population trend of natural enemies

#### *Coccinellid*

Coccinellids serve as general predators, targeting soft-bodied insects such as nymphs of sucking pests and eggs of lepidopteran species. The activity of coccinellids was observed throughout the crop season, with their numbers remaining particularly high at the initial stage of the crop when sucking pests infest the crop most abundantly. It is a common observation that as the population of sucking pests increases, the population of coccinellids also tends to rise. Nevertheless, higher densities were noted during the 32nd to 41st SMW (the second week of August to the second week of October) (Table 9). Comparatively higher numbers of coccinellids were observed during 2013–2014, followed by 2010–2011. The overall data reveals the regular occurrence of coccinellids in the cotton agro-ecosystem (Table 10).

#### *Lacewing*

Lacewing is a highly active predator in the cotton agro-ecosystem, primarily preying on sucking pests. Despite the densities of lacewings across various seasons and years, the population of lacewings remained consistently low, recording a number below 0.13 per plant (Tables 9 and 10).

#### *Spider*

The spider population started to increase from the 31st SMW (the first week of August) and remains fluctuating throughout the crop season. A peak activity was observed during the 34th to 52nd SMW (mid-August to the end of December) (Table 9). The highest annual mean population number of spiders per plant, reaching 0.59, was recorded during 2012–2013 (Table 10).

### Relative occurrence of insect pests and natural enemies among cotton species

#### *Relative occurrence of bollworms and tobacco caterpillar among cotton species*

The infestations of cotton bollworm, spotted bollworm, and tobacco caterpillar were negligible on all the cultivars of cotton under both protective and unprotected conditions (Table 1). During the period of investigations, the majority of the area was dominated by Bt-cotton, this suggests that the technology remains effective in providing ample protection against the aforesaid lepidopteran pests. Destructive sampling for pink bollworm was not conducted, as one of the genotypes was Bt-cotton (RCH2 BG II), although it was designated as a susceptible check for sucking pests in the Central and South zones by the All India Coordinated Crop Improvement Project on Cotton.

#### Relative occurrence of cotton aphid among cotton species

The cotton aphid population was found to be significantly higher in unprotected plots (6.09 aphids per 3 leaves) as compared with protected plots (3.52 cotton aphids). Interaction effects of the main factor (protection

**Table 8** Multiple linear regression between mean weekly onion thrips population per 3 leaves and mean weekly values of weather factors at one-week lag during cotton growing seasons from 2009 to 2019 at Nagpur, Maharashtra

| Parameters | Coefficients | Std. error | *t* test | *P* | $r^2$ | *df* | *F* | Sig. of *F* |
|---|---|---|---|---|---|---|---|---|
| Intercept | – 2.38 | 8.27 | −0.29 | 0.776 | 0.66 | 4, 21 | 10.01 | 0.0001 |
| $b_1$ ($T_{max}$) | 0.38 | 0.21 | 1.82 | 0.083 | | | | |
| $b_2$ ($T_{min}$) | – 0.28 | 0.17 | −1.64 | 0.115 | | | | |
| $b_3$ ($RH_{max}$) | −0.17 | 0.10 | −1.65 | 0.114 | | | | |
| $b_4$ ($RH_{min}$) | 0.21 | 0.06 | 3.77 | 0.001 | | | | |

**Table 9** Seasonal mean population trend of natural enemies in the cotton crop season

| SMW | Corresponding days of SMW | Coccinellids per plant | Lacewings per plant | Spiders per plant |
|---|---|---|---|---|
| 30 | 23 Jul – 29 Jul | 0.28 ± 0.24 | 0.00 ± 0.00 | 0.04 ± 0.00 |
| 31 | 30 Jul – 05 Aug | 0.22 ± 0.04 | 0.00 ± 0.00 | 0.18 ± 0.06 |
| 32 | 06 Aug – 12 Aug | 0.54 ± 0.25 | 0.08 ± 0.05 | 0.16 ± 0.04 |
| 33 | 13 Aug – 19 Aug | 0.67 ± 0.16 | 0.01 ± 0.01 | 0.19 ± 0.04 |
| 34 | 20 Aug – 26 Aug | 0.38 ± 0.08 | 0.01 ± 0.01 | 0.32 ± 0.09 |
| 35 | 27 Aug – 02 Sep | 0.36 ± 0.12 | 0.04 ± 0.04 | 0.32 ± 0.10 |
| 36 | 03 Sep – 09 Sep | 0.42 ± 0.09 | 0.02 ± 0.02 | 0.48 ± 0.08 |
| 37 | 10 Sep – 16 Sep | 0.31 ± 0.09 | 0.12 ± 0.12 | 0.57 ± 0.11 |
| 38 | 17 Sep – 23 Sep | 0.30 ± 0.10 | 0.13 ± 0.10 | 0.53 ± 0.13 |
| 39 | 24 Sep – 30 Sep | 0.36 ± 0.17 | 0.01 ± 0.01 | 0.52 ± 0.19 |
| 40 | 01 Oct – 07 Oct | 0.35 ± 0.11 | 0.07 ± 0.02 | 0.59 ± 0.15 |
| 41 | 08 Oct – 14 Oct | 0.40 ± 0.21 | 0.04 ± 0.03 | 0.55 ± 0.15 |
| 42 | 15 Oct – 21 Oct | 0.27 ± 0.14 | 0.01 ± 0.01 | 0.39 ± 0.12 |
| 43 | 22 Oct – 28 Oct | 0.21 ± 0.06 | 0.00 ± 0.00 | 0.45 ± 0.12 |
| 44 | 29 Oct – 04 Nov | 0.26 ± 0.08 | 0.02 ± 0.01 | 0.48 ± 0.13 |
| 45 | 05 Nov – 11 Nov | 0.13 ± 0.03 | 0.00 ± 0.00 | 0.23 ± 0.06 |
| 46 | 12 Nov – 18 Nov | 0.27 ± 0.08 | 0.01 ± 0.01 | 0.44 ± 0.11 |
| 47 | 19 Nov – 25 Nov | 0.36 ± 0.15 | 0.01 ± 0.01 | 0.61 ± 0.19 |
| 48 | 26 Nov – 02 Dec | 0.06 ± 0.03 | 0.00 ± 0.00 | 0.21 ± 0.13 |
| 49 | 03 Dec – 09 Dec | 0.18 ± 0.06 | 0.00 ± 0.00 | 0.28 ± 0.08 |
| 50 | 10 Dec – 16 Dec | 0.14 ± 0.10 | 0.00 ± 0.00 | 0.28 ± 0.12 |
| 51 | 17 Dec – 23 Dec | 0.22 ± 0.14 | 0.00 ± 0.00 | 0.52 ± 0.32 |
| 52 | 24 Dec – 31 Dec | 0.35 ± 0.19 | 0.00 ± 0.00 | 0.64 ± 0.04 |
| 1 | 01 Jan – 07 Jan | 0.37 ± 0.29 | 0.00 ± 0.00 | 0.31 ± 0.23 |
| 2 | 08 Jan – 14 Jan | 0.30 ± 0.30 | 0.00 ± 0.00 | 0.25 ± 0.25 |
| 3 | 15 Jan – 21 Jan | 0.12 ± 0.12 | 0.00 ± 0.00 | 0.33 ± 0.33 |
| 4 | 22 Jan – 28 Jan | 0.03 ± 0.03 | 0.00 ± 0.00 | 0.37 ± 0.37 |

*SMW* standard meteorological week. Data represent mean ± standard error

**Table 10** Annual mean population of natural enemies over the years 2009–2019

| Year | Coccinellids per plant | Lacewings per plant | Spiders per plant |
|---|---|---|---|
| 2009–2010 | 0.17 ± 0.05 | 0.00 ± 0.00 | 0.59 ± 0.11 |
| 2010–2011 | 0.48 ± 0.05 | 0.00 ± 0.00 | 0.20 ± 0.05 |
| 2011–2012 | 0.39 ± 0.11 | 0.06 ± 0.06 | 0.28 ± 0.09 |
| 2012–2013 | 0.38 ± 0.08 | 0.03 ± 0.02 | 0.74 ± 0.11 |
| 2013–2014 | 0.49 ± 0.10 | 0.10 ± 0.05 | 0.65 ± 0.07 |
| 2014–2015 | 0.22 ± 0.05 | 0.02 ± 0.01 | 0.30 ± 0.06 |
| 2015–2016 | 0.11 ± 0.04 | 0.02 ± 0.01 | 0.15 ± 0.03 |
| 2016–2017 | 0.13 ± 0.05 | 0.00 ± 0.00 | 0.14 ± 0.03 |
| 2017–2018 | 0.41 ± 0.18 | 0.01 ± 0.01 | 0.23 ± 0.04 |
| 2018–2019 | 0.46 ± 0.14 | 0.04 ± 0.02 | 0.32 ± 0.05 |
| 2019–2020 | 0.22 ± 0.03 | 0.01 ± 0.00 | 0.43 ± 0.06 |

Data represent mean ± standard error

treatment) with sub-factors (cultivars) were found significant. Among various cultivars evaluated, Phule Dhanvantary recorded the lowest aphid population which was at par with Suvin. Cultivars RCH2, Suraj, and DCH 32 were not significantly different from each other and had relatively higher aphid populations (Table 11).

***Relative occurrence of cotton jassid among cotton species***

The cotton jassid population was found to be significantly higher in unprotected plots (7.57 cotton jassid per 3 leaves) as compared with protected plots (4.80 cotton jassid per 3 leaves). Amongst the cultivars, Phule Dhanvantary was found to be the most tolerant among the cultivars with minimum jassid counts (1.83 cotton jassid per 3 leaves). This was followed by Suraj and RCH 2 with significant differences in jassid counts between the two cultivars, but both cultivars had significantly lower cotton jassid than Suvin and DCH32 cultivars (Table 11).

***Relative occurrence of cotton whitefly among cotton species***

Significant variation was observed from the data on protected (1.13 whitefly per 3 leaves) and unprotected plots (2.11 whitefly per 3 leaves) on the population of whitefly. The main effect of cultivars was also found to be significant, however, Phule Dhanvantary, DCH 32, and Suraj which had comparatively lower but not significantly different populations compared with RCH 2 and Suvin (Table 11).

***Relative occurrence of onion thrips among cotton species***

Significant variation in onion thrips counts was observed from the protected (2.27 thrips per 3 leaves) and unprotected plots (4.15 thrips per 3 leaves). Interaction effect also shows a significant effect of cultivars indicated the lowest thrips population on Phule Dhanvantary (1.22 thrips per 3 leaves) and different from rest of cultivars. This was followed by Suvin (2.35 thrips per 3 leaves) and Suraj (3.32 thrips per 3 leaves), both were not significantly different from each other. Comparatively higher and identical onion thrips population was recorded on DCH 32 and RCH 2 (Table 11).

***Relative occurrence of mirid bug among cotton species***

Despite the statistically significant difference between protected plots reporting 0.07 mirid bugs per plant and unprotected plots with 0.30 bugs per plant, among cultivars, the population of mirid bugs remained minimal range from 0.03 to 0.16 except for Suraj (0.52 per plant) which occurred comparatively higher population and was significantly different from the rest of cultivars (Table 11).

***Relative occurrence of spiders among cotton species***

The spider population recorded from protected and unprotected plots have yielded significant differences between 0.22 and 0.43 spiders per plant, respectively. There was no significant difference among the five cotton cultivars (Table 11).

## Discussion

Arthropod pests pose a significant threat to cotton yields, spanning from the initial sowing stage to the final harvest (Abro et al. 2004). The timing of pest activity, particularly its increase towards a peak during specific crop growth stages, holds paramount importance in effective pest management. A proactive approach by growers, informed about the pest's peak activity, facilitates the implementation of timely and targeted control measures. The intervention during the right stage of pest development simplifies the management process. Conversely, delayed decision-making and subsequent action may yield unsatisfactory results, leading to escalated input

**Table 11** Seasonal incidence of sucking pests and spider population on different cotton cultivars (Pooled over years 2016—2018)

| Sources of variation | Cotton aphid per 3 leaves | Cotton jassid per 3 leaves | Cotton whitefly per 3 leaves | Onion thrips per 3 leaves | Mirid bug per top one-third portion | Spiders per plant |
|---|---|---|---|---|---|---|
| **Main plot treatment** | | | | | | |
| Protected | $3.52 \pm 0.34^{a}$ | $4.80 \pm 0.64^{a}$ | $1.13 \pm 0.09^{a}$ | $2.27 \pm 0.41^{a}$ | $0.07 \pm 0.02^{a}$ | $0.22 \pm 0.02^{a}$ |
| Unprotected | $6.09 \pm 0.61^{b}$ | $7.57 \pm 0.87^{b}$ | $2.11 \pm 0.10^{b}$ | $4.15 \pm 0.38^{b}$ | $0.30 \pm 0.09^{b}$ | $0.43 \pm 0.02^{b}$ |
| **Sub plot treatment (Cultivar)** | | | | | | |
| DCH 32 | $6.28 \pm 1.15^{b}$ | $9.29 \pm 1.28^{d}$ | $1.59 \pm 0.34^{ab}$ | $4.58 \pm 0.35^{c}$ | $0.16 \pm 0.05^{a}$ | $0.40 \pm 0.06^{a}$ |
| RCH 2 | $5.42 \pm 0.49^{b}$ | $6.36 \pm 0.78^{c}$ | $1.69 \pm 0.13^{b}$ | $4.58 \pm 0.38^{c}$ | $0.03 \pm 0.01^{a}$ | $0.28 \pm 0.07^{a}$ |
| Phule Dhanvantary | $2.70 \pm 0.40^{a}$ | $1.83 \pm 0.42^{a}$ | $1.32 \pm 0.32^{a}$ | $1.22 \pm 0.33^{a}$ | $0.11 \pm 0.03^{a}$ | $0.34 \pm 0.06^{a}$ |
| Suraj | $6.15 \pm 0.96^{b}$ | $4.82 \pm 0.36^{b}$ | $1.63 \pm 0.14^{ab}$ | $3.32 \pm 0.88^{b}$ | $0.52 \pm 0.19^{b}$ | $0.29 \pm 0.05^{a}$ |
| Suvin | $3.47 \pm 0.52^{a}$ | $8.64 \pm 0.50^{d}$ | $1.86 \pm 0.29^{b}$ | $2.35 \pm 0.48^{b}$ | $0.11 \pm 0.02^{a}$ | $0.32 \pm 0.04^{a}$ |
| **Variance ratio (*F*)** | | | | | | |
| Main plot treatment | 26.977* | 293.587** | 51.360* | 189.543** | 19.177* | 64.641* |
| Sub plot treatment | 14.628*** | 202.728*** | 4.319* | 37.909*** | 22.585*** | NS |
| Main plot treatment × Sub plot treatment | 3.433* | 6.904** | 4.519* | 4.611** | 11.478*** | NS |
| $r^2$ | 0.885 | 0.985 | 0.907 | 0.941 | 0.921 | 0.792 |

* represents significant at the 0.05 level, ** represents significant at the 0.01 level, *** represents significant at the 0.001 level. Data represent mean ± standard error

Means within a column followed by the same letter superscripted do not differ significantly ($P < 0.05$, Tukey HSD test), *NS* non-significant costs and diminished effectiveness of control measures (Sunding et al. 2000).

The cotton bollworm population exhibited low densities throughout the seasons in this study, aligning with the findings of Dhawan (2016), wherein a significant reduction was observed in cotton bollworm infestations since 2000. They stated that the decline was attributed to several factors such as, introduction of new insecticides, a decrease in the use of synthetic pyrethroids insecticides, and the adoption of Bt-cotton. The low pheromone trap catches further support the reduced infestation observed in the cotton growing seasons from 2009 to 2019. In contrast, prior to the year 2000, outbreaks of the cotton bollworm were documented in several states, *e.g.* Maharashtra, Gujarat, Andhra Pradesh, Punjab, Haryana, Rajasthan, and Madhya Pradesh (Dhawan 2016). Noticeably, there has been a visible shift in the larval population of cotton bollworm, recorded between mid-September and the last week of November (Nagendra et al. 2015), which is consistent with the findings of the current study. Moreover, the population of the spotted bollworm remained in trace throughout these years. The cultivation of Bt-cotton in India on a substantial scale significantly impacted this pest. The population of spotted bollworm scarcely exceeded the ETL during crop seasons and consistently maintained low numbers, akin to cotton bollworm. As a result, spotted bollworm requires comparatively less attention due to its limited impact on cotton crops.

The incidence of pink bollworm infestation remained negligible until the 2016–2017 period but surged to its highest levels in 2017–2018 due to a sudden outbreak linked to the development of resistance in transgenic cotton. This alarming trend aligns with the findings of Fand et al. (2019a), who extensively documented a widespread infestation of pink bollworm on Bt-cotton in Central India, highlighting a burgeoning threat and raising concern for cotton production. The peak activity of pink bollworms, notably observed from October onward, starting from the $45^{th}$ SMW, aligns with the observations of Naik et al. (2018). Concurrently, a substantial number of pheromone trap catches, coinciding with the flowering and fruiting stage, indicated a population buildup from October onward, as noted by Verma et al. (2017). Our results showed a correlation between the onset of field damage of pink bollworm and moth catches in pheromone traps recorded two weeks prior to the damage, which corroborates with the previous research on pink bollworms (Fand 2021; Fand et al. 2021). Given the breakdown of Bt-cotton resistance to pink bollworm and the absence of alternative technologies, there is a pressing need to devise an integrated pest management program. This program should encompass various methods such as cultural practices, behavioral strategies, biopesticides, chemical pesticides, etc. A community-wide approach becomes crucial for effective implementation (Mohan 2017; Nagrare et al. 2023).

Despite a substantial number of pheromone trap catches of tobacco caterpillar in cotton fields, the observed damage was negligible to the cotton crop suggesting a lack of correlation between trap catches and plant infestation. Although the peak activity of tobacco caterpillar was noted during the 32–39 SMW, the absence of damage potential implies that cultivators can currently afford to allocate less attention to this pest. Previous reports indicated outbreaks of tobacco caterpillar in South India during 1995–2000, primarily attributed to the excessive use of insecticides, especially synthetic pyrethroids (Kranthi et al. 2002). The present scenario, marked by trap catches not translating into significant crop damage, underscores the evolving dynamics of pest management and highlights the need for growers to adapt their attention and resources based on current threat levels.

While the aphid population persists in the field throughout the cropping season, its peak activity is notably recorded during the 32nd SMW, specifically from 6 to 12th August. This timeframe demands heightened vigilance in the context of pest management. These findings align with the reports of Nemade et al. (2018), indicating consistency in the observed patterns. However, there is a slight deviation in the duration of peak occurrence towards the end of August, as reported by Dhobi et al. (2013) and Nagendra (2015). Taking proactive measures during this critical period is essential for delaying population buildup. Failure to act during this window may result in a widespread increase in aphid population across the entire field, as noted by previous studies (Hanumantharaya et al. 2008; Godhani et al. 2009; Babu et al. 2014). In our investigations, multiple linear regression analysis revealed a significant negative influence of maximum temperature and morning relative humidity on aphid population build up. The current research results are consistent with Akhila et al. (2020) who reported a negative correlation with the majority of abiotic factors and a positive correlation with minimum temperature.

Cotton jassid, a recurrent pest in cotton cultivation, exhibited notable numbers between the $32^{nd}$ and $38^{th}$ SMW, peaking at the $36^{th}$ SMW–a trend consistent with prior findings (Laxman et al. 2014; Nemade et al. 2018). However, divergent reports indicated peak occurrences of cotton jassid from the $38^{th}$ to $45^{th}$ SMW, with activity extending into October (Bharpoda et al. 2013; Soni et al. 2016). In the Marathwada region, the highest cotton jassid counts were recorded during the third week of September (Nagendra 2015). Data from yellow sticky trap catches underscored the highest numbers of cotton jassid trapped between the 34th and 45th SMW, with the peak observed at the 43rd SMW, followed closely by the 45th SMW. Multiple linear regression in our current study revealed $T_{\max}$ and $RH_{\min}$ significantly positively influenced jassid population buildup, while $T_{\min}$ exhibited a significantly negative influence. Similar findings were also reported by Patel et al. (2018). Effective management of this pest demands attention, given its potential to cause significant yield losses by weakening the health of affected plants. The withdrawal of sprays against bollworms has shifted the focus toward sucking pests, particularly cotton jassid, during the critical flowering and boll development stages.

Since 2009, the infestation of whitefly has consistently remained below the ETL in areas where prudent insecticide applications have been strategically implemented. These outcomes align with earlier findings (Deb et al. 2013; Nemade et al. 2018). Yellow sticky trap data revealed peak adult catches between the 37th and 45th SMW, with the highest recorded at the 43rd SMW, followed closely by the 42nd SMW. Despite these trap catches, on the plants within the experimental block, cotton whitefly densities remained low. In contrast, areas with indiscriminate application of tank-mixed insecticides in farmers' fields have experienced high cotton whitefly infestation (Kumar et al. 2024). The present study recorded a relatively lower impact (52.00%) of weather factors on whitefly population fluctuations in the multiple linear regression model while Janu et al. (2017a) reported 64.90% and 79.50% during 2014 and 2015, respectively. This suggests a varying degree of influence from weather conditions on whitefly populations over the years.

Thrips occurrence aligns with the observations of previous researchers where onion thrip populations are recorded between the 34th and 37th SMW, ranging from the last week of August to mid-September (Soujanya et al. 2010; Nagendra 2015; Nemade et al. 2018). However, our findings diverge from the observations of Padaliya et al. (2018), who reported increased onion thrips activity during November and December, with the peak occurring in the second week of December. In the current investigation, multiple linear regression revealed a 66.00% impact of weather factors, demonstrating a notable influence on mean weekly onion thrip population levels. These results are similar with conclusions reported by Janu et al. (2017b), who documented a 58.20% impact during 2014 and a 71.60% impact during 2015. This emphasizes the dynamic relationship between weather conditions and onion thrip population dynamics, highlighting the need for nuanced pest management strategies. From the present investigations, it is comprehensible that the population of most of the sucking pests was maximum during the initial plant growth period and it declined towards the later crop growth stages.

In the presence of an abundant prey population, the density of natural enemies, including coccinellids, lacewings, and spiders, remains substantial during the early crop development stages, fluctuating in response to the availability of food in the cotton field. These results are consistent with the observations made by Nagendra (2015). It is notable that the spider population peaked during the second fortnight of October to the first fortnight of November, precisely coinciding with the boll development stage.

The cultivars from three species of cultivated cotton varied in reactions to pests and natural enemies. The response of cultivated cotton to pests is influenced by the genetic makeup of the genotype (Boote et al. 1983; Aggarwal et al. 2006). Genotypes such as DCH 32, RCH 2, and Suraj displayed susceptibility to aphid populations, whereas the lowest aphid count was recorded in Phule Dhanwantary and followed by Suvin. Notably, it is worth mentioning that the aphid population has exhibited a declining trend since 2009. Our findings, however, diverge from those of Phulse et al. (2014), who reported higher mean densities of cotton aphids in *desi* cotton hybrids, followed by inter-specific hybrids and intra-specific hybrids. The diverse responses observed among the evaluated cultivars can be attributed to disparities in their morphological characteristics, biochemical content, and other influencing factors.

Cultivars Suvin and DCH 32, as well as the hybrid RCH 2 (*G. hirsutum* × *G. barbadense*), were high susceptible to cotton jassid, while the population was the least on Phule Dhanvantary (*G. arboreum*). This result suggests that *G. arboreum* is tolerant to cotton jassid, whereas cultivars derived from *G. hirsutum* and *G. barbadense* are highly susceptible. In contrast, the straight variety of *G. hirsutum* (Cv. Suraj) demonstrated a moderate level of tolerance to cotton jassid.

Across various cotton cultivars, the whitefly population remained consistently below the ETL throughout the three years, and statistical analysis revealed significant differences between the selected cultivars. Phule Dhanwantary was found to be the most tolerant cultivar of whitefly. Similarly, the cotton cultivar Phule Dhanvantary also exhibited the least onion thrips population, consistently remaining well below the ETL over the three-year period. Consequently, under current circumstances, where cotton whitefly and onion thrip populations are insufficient for meaningful distinctions, it is challenging to categorize identified cultivars as either resistant or tolerant. Furthermore, mirid bug, with negligible populations recorded across all cultivars, require minimal attention in terms of pest control. This suggests that, at present, the identified cultivars show resilience against mirid bug, contributing to a more balanced and manageable pest control scenario. The cultivation of pest-resistant cultivars emerges as a crucial determinant contributing factor to the success of integrated pest management strategies.

## Conclusions

Cotton bollworm, spotted bollworm, and tobacco caterpillar were observed in small levels, while pink bollworm caused significant damage to cotton during the cropping season of 2017–2018. The population of most sucking pests was at higher densities during the initial plant growth period, gradually declining in later growth stages. Cotton jassid emerged as a regular pest, and remain active from August to September, causing substantial damage. Conversely, cotton whitefly and onion thrip infestations remained below the ETL. Mirid bug populations coincided with square and flower formation but caused insignificant damage to the cotton crop. Natural enemies were abundant initially, fluctuating based on food availability in the cotton field. Multiple linear regression analysis indicated a significant impact of mean weekly weather factors at one- or two-week lags on the fluctuation of sucking pest populations. Cultivars RCH 2, DCH 32, and Suvin displayed susceptibility to cotton aphid, cotton jassid, and onion thrips. Phule Dhanwantary emerged as the most tolerant cultivar against all sucking pests in cotton. This information proves valuable in the selection of cotton cultivars, guiding subsequent plant protection measures to minimize crop damage effectively.

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**Authors' contributions**

Nagrare VS and Naikwadi B conceived and designed research. Nagrare VS, Naikwadi B, and Tenguri P conducted experiments. Nagrare VS, Naikwadi B, Naik VCB, and Tenguri P compiled data. Nagrare VS and Fand BB analyzed data. Nagrare VS, Gokte-Narkhedkar N, and Waghmare VN supervised work. Nagrare VS Fand BB, and Naik VCB wrote the manuscript. Gokte-Narkhedkar N and Waghmare VN reviewed and edited manuscript. All authors read and approved the final manuscript.

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## Declarations

**Ethics approval and consent to participate**

Not applicable.

**Consent for publication**

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**Competing interests**

The authors declare that they have no competing interests. Author Fand BB is a member of the Editorial Board of Journal of Cotton Research. Author Fand BB was not involved in the journal's review of, or decision related to this manuscript.

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