*Original Research Article*

Off-season activity and seed cotton infestation of pink bollworm (*Pectinophora gossypiella* Saunders*)* at ginneries of South Gujarat

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ABSTRACT

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| The off-season activity of male moths of cotton pink bollworm was studied at Research Farm, NAU, Surat and five ginneries through installing pheromone traps during January to June 2022 in South Gujarat. The activity of male moths of pink bollworm were observed throughout the year (January to December 2022) at Research Farm and was more pronounced during 1st to 13th Standard Meteorological Weeks (SMW) and 38th to 51st SMW coinciding with the fruiting stages of the crops in the field and less pronounced (<8 male moths/trap) when crops unavailable in the fields. The moth activity showed significant positive correlation with sunshine hour and negative correlations with minimum and average temperature; morning and average relative humidity and rainy days. In five ginneries, male moth activity varied considerably during off-season. At ginning mill, Olpad, Surat, the activity was noticed from 1st to 16th SMW with peak in 8th SMW (av.8 moths/trap). In Bharuch districts, the trap catches were observed from 1st to 16th SMW being peak in 7th SMW (av. 14 moths/trap) at ginning mill, Hansot, whereas it was observed from 1st to 21st SMW and 1st to 24th SMW at Sikhar and Laheri ginning mills, respectively being peak in 7th SMW (av. 14 moths/trap). At Vipul ginning mill, Karjan, the trap catches were noticed from 1st to 23rd SMW and peak during 7th SMW (av. 12 moths/trap). The previous and fresh stock supply of raw seed cotton at ginneries was initiated from October and actual ginning process started in the November or December depending on the optimum stock. The overall infestation to seeds was found 7.41, 9.21, 11.38, 14.79 and 11.62 per cent at respective ginneries. Infested seeds were found more in North (13.79%) than other three directions (8.67 to 11.96%) in the heap of seeds. Live larvae/pupae were recovered more from single seeds (8.6 larvae) than in double seeds (4.7 larvae/pupae) indicating advancement of generation rather to enter in diapausing stage in double seeds. |

*Keywords: Moth activity and Infestation of pink bollworm*,*Cotton ginneries*

1. INTRODUCTION

In India, cotton is mainly grown in Gujarat, Maharashtra, Telangana, Andhra Pradesh, Madhya Pradesh, Punjab, Tamil Nadu and Karnataka. In terms of area under cultivation, the country is leading accounting for about one fourth of the total world cotton area. In India, cotton occupies an estimated area of 130.49 lakh ha with an annual production of 337.23 lakh (1 bales = 170 kg) and productivity of 439 kg/ha. In Gujarat, cotton occupies an estimated area of 25.49 lakh ha with an annual production of 87.12 lakh bales and a productivity of 581 kg/ha. (Anon., 2023).

The issue of ineffectiveness of the endotoxins (Cry1Ac and Cry2Ab2) of Bt cotton against pink bollworm in 2015-16 and increasing use of insecticides again lead threat to the technology. Naik et al. (2018). reported the field evolved resistance ratio of 26 to 262-fold in pink bollworm to Cry1Ac and 1 to 108 folds to Cry2Ab2 from 2010 to 2017 in Central and Southern India. Even the population of pink bollworm in Northern India showed resistance to toxins in recent past. The faster evolution of resistance to endotoxins (Cry1Ac and Cry2Ab2) in commercial Bt cotton, mainly attributed to non- compliance of refuge strategy and lower concentration of Cry1Ac resulted in major yield losses or shifts in strategies in India (Tabashnik et. al., 2013 and Wan et al., 2017). The cotton yield is reduced by 3 to 5 q/ha as a result of a steady rise in its incidence and resulting low-quality lint. Since young larvae enter the cotton bolls throughout its development stage and remain inside by feeding on the developing seeds, it is difficult by the farmers to detect incidence on account of internal feeding behaviour. The damage is apparently visible when bolls are matured and burst and bad opened bolls with damaged seeds are noticed. The stubbles and damaged bolls left in cotton fields for an extended period of time could support pest survival in the off-season and serve as a crucial link in the pest's ability to spread and carry over to next season reported earlier (Jayaswal, 1971 and Simwat and Sidhu, 1982). Similarly, harbouring of live larvae in gin trash piled up in different ginneries was also noticed to spread infestation in the next season (Nandal, 1983).

Being the internal pest, the easy way to detect the presence of pink bollworm is through installation of pheromone traps that attract male moths. The use of sex pheromones includes identification of pheromones, development of dispensers and traps, assessment of pheromone traps as a monitoring device, and the use of pheromones for mating disruption. Besides monitoring, the male moth catches of pink bollworm in gossyplure-baited traps were also used to predict larval infestation (*P. gossypiella*) in cotton fields (Staten and Walters, 2021). Mass trapping of moths with pheromone-sleeve traps @50 and 20 traps/ha with change of lure at 45 day- interval were found effective in reducing infestation and damage of pink bollworm at Guntur (Lakshmi et al., 2023). The continuous mono-cropping and availability of Bt cotton plants throughout the year in one part or other parts as well as extending crop season for multiple pickings especially in irrigated region provides congenial climate for spread and multiplication of pink bollworm and yield losses. Garg et al. (2022) reviewed the reasons for resistance evolution in pink bollworm to transgenic cotton and opined that the management of resistance in PBW requires a broader vision in developing IPM/IRM technology. The significant yield loss up to 36.2 per cent was reported due to the pink bollworm and other sucking pests (Bhute et al., 2023). The application of potash mobilizing bacteria (KMB) @2.5 litre ha-1 at 15 days after sowing and foliar sprays of potassium nitrate (KNO3) @3% during squaring (60DAS), flowering (75DAS) and boll development stages (90DAS) on early maturing G. Cot. Hy. 8 BG II provided effective protection of spotted and American bollworm and reduced spray against pink bollworm showing effective expression of genes at 90 DAS (Parmar et al*.,* 2024). The long processing in the ginning and pressing industries during the off-season may provide survival of residual population which led to initial source for the next season. Thus, there is need to monitor the activity of pink bollworm in off-season survival in ginning factories and fields on alternate hosts, on extended crops, in field residues and stored cotton sticks on the field border in spread and carry over. Hence, investigations were carried out on off-seasonal activity of moths of pink bollworm (Pectinophora gossypiella Saunders) through pheromone traps in south Gujarat

2. material and methods

The activity of pink bollworm was monitored throughout the calendar year (off-season and cotton season) at Research Farm by installing pheromone traps (Phero-sensor TM-SP sleeve trap) @ 5 traps/ha and the lure for pink bollworm was changed as prescribed interval (40 days) in the reserved land from January to June and later in the season in unprotected plots (having hybrid, G. Cot. Hy. 8 BG II spaced at 1.20 x 0.45 m in approximate 4000 sq. m) kept for studying incidence of insect pests. The care was undertaken to install the pheromone traps along the cotton row at 1 foot above the canopy height keeping the isolation distance of 30 m between two traps. The male moth catches of pink bollworm were recorded from each of the installed traps at one-week interval throughout the year during off-season and season and the average male moths trapped per week during entire year were estimated. Similarly, the off-season monitoring for emergence of moths at courtyard of ginneries through installing pheromone traps for attracting male moths of pink bollworm was carried out at total five ginning mills of south Gujarat (Fig.1), from the receipt of fist supply of seed cotton (November-December) to close of ginning process and onset of new season The locations were depicted on maps in Fig. 2 and Fig. 3 and the detail of each location with name of ginneries and GPS was given in Table 1. The care was undertaken to install the pheromone traps along the cotton heaps height keeping the isolation distance of 30 m between two traps (Fig.4). The correlation studies with weekly weather parameters (max. temp., min. temp., morning RH, evening RH, sunshine hours, wind speed. rainfall, rainy days), obtained from the Meteorological Observatory of Main Cotton Research Station, NAU, Surat and Regional Cotton Research Station, NAU, Bharuch were carried out for respective locations.

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| **Fig. 1: Gujarat state map showing locations of ginneries in Surat and  Bharuch district** | * Yashvantrai Joshi Ginning and Pressing Mill * Vipul Ginning Mill * Laheri Cotton Industries * Shikhar Cotton Industries   **Fig. 2: Close up view of Bharuch district map showing four different ginneries** |
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| * Ginning and Pressing Mill, Olpad   **Fig. 3: Close up view of Surat district map showing co-operative ginning mill** | **Fig. 4: Installation of PBW pheromone trap at ginning mill** |

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| **Table 1: Study sites for off-season survival of cotton pink bollworm in south Gujarat   (Ginneries, Villages and Research Farms)** | | | | | |
| **Sr. No** | **Name of the district** | **Name of the taluka** | **Name of the ginning factory/Research Farm** | **GPS location of ginning factories** | |
| **Latitude** | **Longitude** |
| **Ginneries** | | | | | |
| 1 | Surat | Olpad | G1-Ginning and Pressing  Mill | 21˚19’39’8’’N | 72˚45’36.4’’E |
| 2 | Bharuch | Hansot | G2-Yashvantrai Joshi  Ginning and Pressing   Mill | 21˚35’4’’N | 72˚48’45’’E |
| 3 | Palej | G3-Shikhar Cotton   Industries | 21˚55’33’’N | 73˚4’9’’E |
| 4 | Palej | G4-Laheri Cotton Industries | 21˚55’17’’N | 73˚3’51’’E |
| 5 | Karjan | G5-Vipul Ginning-Pressing  and oil mill | 22 ˚048840 N | 73.113996 E |
| **Research farms** | | | | | |
| 6 | Surat | Surat city | Main Cotton Research Station, NAU, Surat | 21˚9’57’’N | 72˚48’1’’E |
| 7 | Bharuch | Bharuch city | Regional Cotton Research Station, NAU, Bharuch | 21˚71126 N | 73˚01265 E |

Further, the presence of larvae/cocoon of pink bollworm was also detected through sampling from ginning outlets heaped in the corner of the courtyard of ginneries wherever available during the survey. The samples of ginning waste/trash stacked in heaps (Fig. 5 and Fig.6) after ginning process was taken in perforated plastic bags from four directions at fortnightly intervals till availability of ginning waste from December to June from selected five ginneries and brought to the laboratory of Main Cotton Research Station, NAU, Surat. From each sample, 50 g of seeds were examined for the presence of diapausing larvae/pupae in single or double seeds. For the purpose, the number of total seeds and infested single or double seeds were counted and within infested seeds, the number of diapausing larva/cocoon was recorded from the samples of each direction and locations.

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| **PBW larva** |
| **Fig. 5: Pink bollworm infestation in gin waste/trash in ginning mill** |
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| **Fig. 6: The heaps of seeds at outlet after ginning process** |

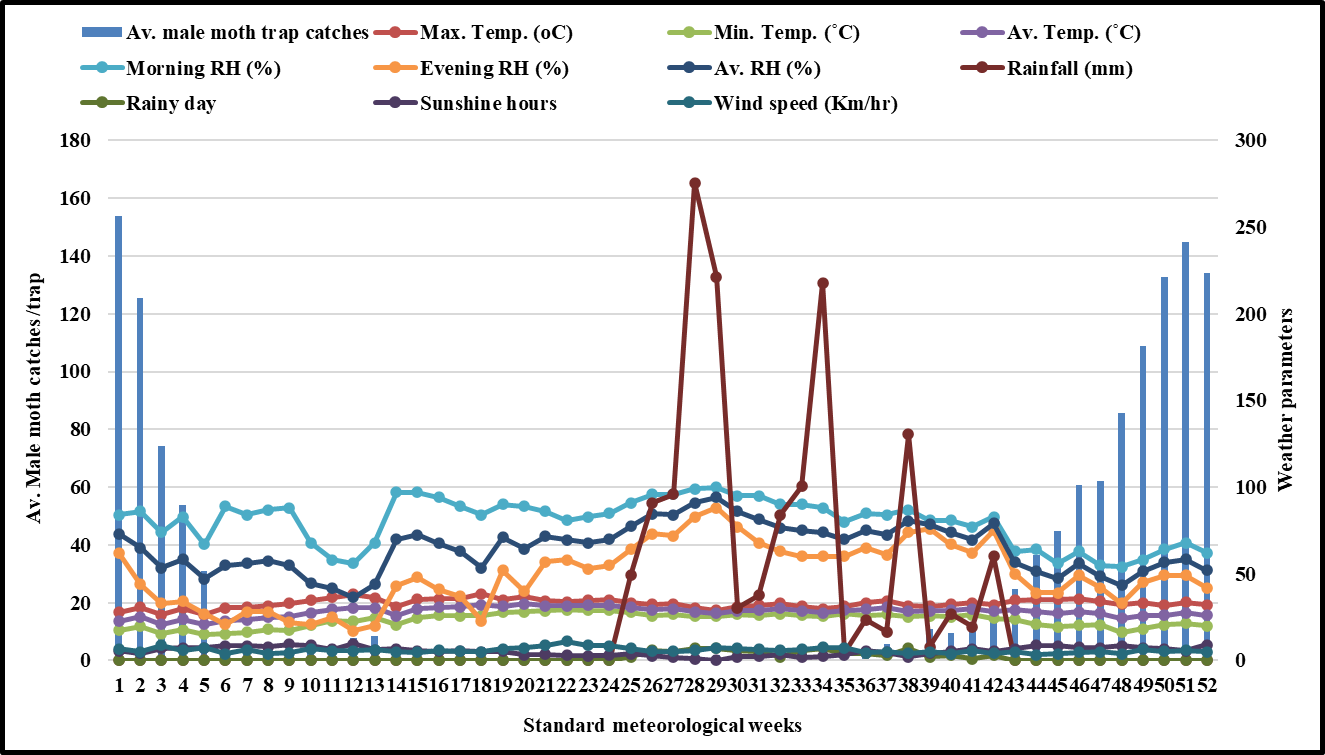
3. results and discussion

results

The data recorded on trap catches through installation of pheromone traps from January to June 2022 on fellow land and from July to December 2022 in the unprotected plots (having hybrid, G. Cot. Hy. 8 BG II spaced at 1.20x0.45 m in approximate 4000 sq. m) kept for studying incidence of insect pests at Research Farm, Main Cotton Research Station, NAU, Surat. Similarly, the trap catches of male moths of pink bollworm in five ginneries monitored through installation of pheromone traps (from January to June 2022 (Cotton off-season) were utilized for correlations studies with abiotic factors recorded at respective jurisdiction of research farm. Further, the infestation of pink bollworm was also recorded in the samples of seeds separated after ginning processing of stored raw seed cotton in the respective ginneries till the availability.

**3.1 Monitoring of pink bollworm activity at Research farm**

The activity of male moths of pink bollworm was noticed throughout the year from January to December 2022 (Fig.7 and Table 2). The pink bollworm moth activity was more pronounced during earlier weeks from 1st to 5th Standard Meteorological Weeks (SMW) being peak on 1st SMW (av. 154 male moths/trap/week) and thereafter, gradually decreased and remained below av. 8 male moths/trap except in 13th SMW till 38th SMW and again started to build up and reached to second peak on 51st SMW (av. 145 moths/trap/week). As far as correlations with weather parameters are concerned, the male moth activity showed significant and negative correlations with minimum temperature, average temperature, morning relative humidity, average relative humidity and rainy days whereas significant and positive correlation with sunshine hour.



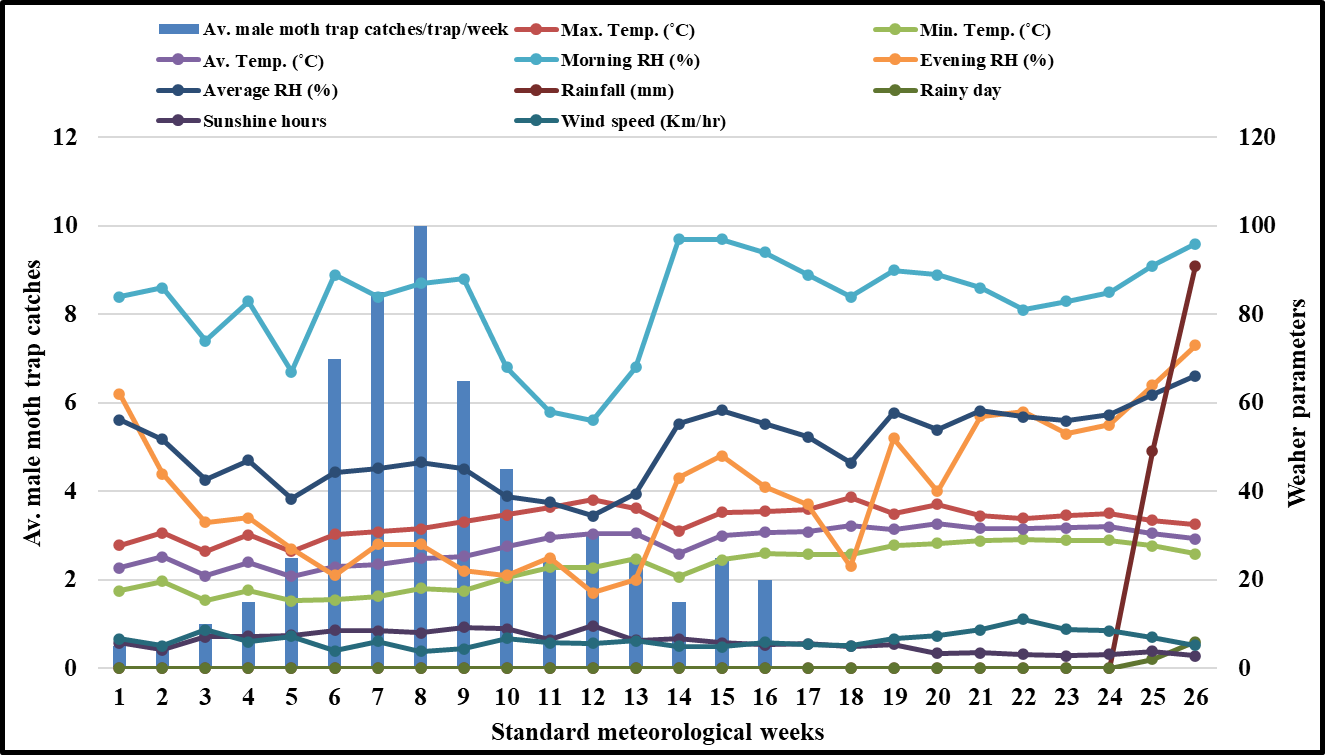
**Fig. 7: Correlation of trap catches of male moths with abiotic factors at Main Cotton Research Station, NAU, Surat**

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| **Table 2: Correlations between trap catches of male moths of pink   bollworm and weather parameters during 2022 (MCRS, Surat)** | | | | |
| **Pink bollworm and weather parameters** | **Minimum** | **Maximum** | **Mean ± S. D.** | **‘r’ values** |
| **Pink Bollworm** | | | | |
| Average trap catches (Male moths/trap/week) | 1.2 | 154 | 27.8±43.7 | 0.0000 |
| **Weather parameters** | | | | |
| Maximum Temperature (0C) | 26.4 | 38.6 | 32.9±2.6 | -0.2604 |
| Minimum Temperature (0C) | 15.2 | 29.1 | 23.2±4.1 | -0.5421\*\* |
| Average Temperature (0C) | 20.8 | 32.6 | 28.1±2.9 | -0.5070\*\* |
| Morning Relative Humidity (%) | 54.0 | 100 | 80.2±13.3 | -0.4986\*\* |
| Evening Relative Humidity (%) | 17.0 | 88.0 | 49.5±18.4 | -0.1351 |
| Average Relative Humidity (%) | 36.5 | 94.0 | 64.9±13.8 | -0.3317\* |
| Rainfall (mm) | 0 | 275.5 | 28.7±61.3 | -0.2693 |
| Rainy day | 0 | 7 | 1.5±2.4 | -0.3562\* |
| Sunshine hour | 0 | 9.6 | 5.4±2.5 | 0.3434\* |
| Wind speed (Km/h) | 3.2 | 11.1 | 5.9±1.5 | -0.1092 |
| Note: Correlation is highly significant\*\* at the 0.01 level and correlation is significant\* at the 0.05 level of significance at n-2 degrees of freedom (No. of observation, n=52) | | | | |

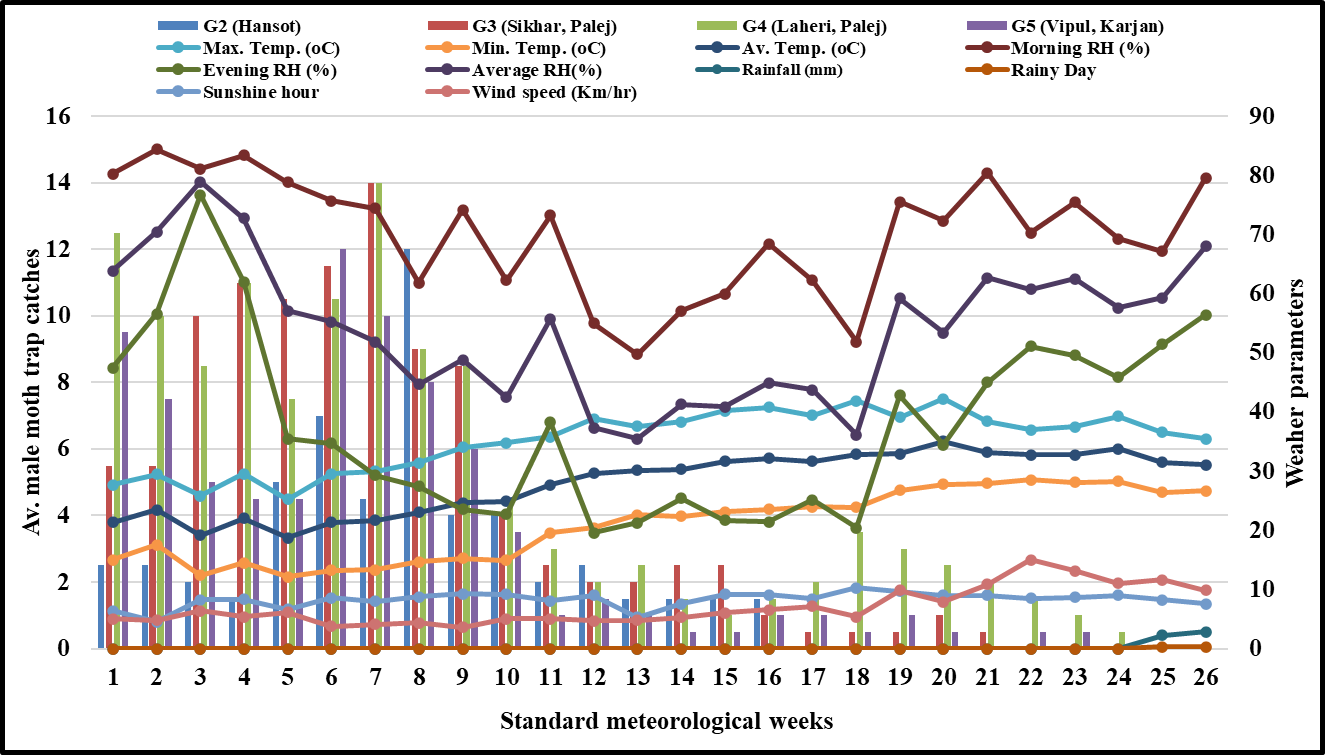
**3.2 Monitoring of pink bollworm activity at ginneries**

Attempt was made to know the incidence of pink bollworm at ginneries within cotton area of Surat and Bharuch districts during cotton off-season. At ginning mill, Olpad, Surat district, the activity of male moths of pink bollworm was noticed from 1st (January first week) to 16th (April fourth week) SMW showing peak during 8th SMW i.e., last week of February (av. 10.0 male moths/trap/week) and there was no activity of male moths during May and June months (Table 3 and Fig. 8). The correlations with weather parameters recorded at nearest observatory of Main Cotton Research Station, NAU, Surat showed significant and negative correlations of trap catches with minimum temperature, average temperature, evening relative humidity, average relative humidity and wind speed whereas highly significant and positive correlations with sunshine hour. At ginning mills of Bharuch districts (Table 3 and Fig. 9), the pink boll was active from 1st (January first week) to 16th (April fourth week) SMW with peak trap catches during 8th SMW i.e., last week of February (av. 10.00 male moths/trap/week) at ginning mill, Hansot whereas it was observed from 1st to 21st SMW with peak catches during 7th SMW (av. 14.00 male moths/trap/week) and 1st to 24th SMW with peak catches during 7th SMW (av. 14.00 male moths/trap/week) at Sikhar and Laheri ginning mills, respectively. At Vipul ginning mill, the pink boll was found active from 1st (January first week) to 23rd (April third week) SMW with peak catches during 7th SMW i.e., last week of February (av. 12.0 male moths/trap/week). The correlations of trap catches of pink bollworm at different ginning mills of Bharuch district (Hansot, Shikhar, Laheri and Vipul) with weather parameters recorded at observatory of Regional Cotton Research Station, NAU, Bharuch showed highly significant and negative correlations with maximum temperature, minimum temperature, average temperature and wind speed at all four locations. However, it showed a significant and positive correlation with morning relative humidity at Laheri ginning mill, Palej, Dist. Bharuch.

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| **Table 3: Correlations of trap catches of male moths at ginneries with abiotic factors during cotton off- season in fields during 2022** | | | | | | |
| **Weather parameters** | **Correlation co-efficient between male moth catches & weather parameters** | | | | |
| **G1-Olpad** | **G2-Hansot** | **G3-Sikhar, Palej** | **G4-Laheri, Palej** | **G5-Vipul, Karjan** |
| Maximum Temperature (0C) | -0.2106 | -0.5520\*\* | -0.7690\*\* | -0.7407\*\* | -0.7793\*\* |
| Minimum Temperature (0C) | -0.6304\*\* | -0.7290\*\* | -0.9090\*\* | -0.8509\*\* | -0.8226\*\* |
| Average Temperature (0C) | -0.4942\* | -0.6770\*\* | -0.9119\*\* | -0.8729\*\* | -0.8396\*\* |
| Morning Relative Humidity (%) | -0.1074 | -0.0157 | 0.3670 | 0.4471\* | 0.3701 |
| Evening Relative Humidity (%) | -0.6036\*\* | -0.2561 | 0.1034 | 0.1658 | 0.0664 |
| Average Relative Humidity (%) | -0.4510\* | -0.1725 | 0.2205 | 0.2945 | 0.1979 |
| Rainfall (mm) | -0.2133 | -0.2263 | -0.2651 | -0.3225 | -0.2471 |
| Rainy day | -0.1982 | -0.2281 | -0.2672 | -0.3251 | -0.2490 |
| Sunshine hour | 0.7599\*\* | -0.0887 | -0.2056 | -0.3076 | -0.2982 |
| Wind speed (Km/h) | -0.5180\*\* | -0.5847\*\* | -0.6155\*\* | -0.6017\*\* | -0.5887\*\* |
| Notes: Correlation is highly significant\*\* at the 0.01 level and correlation is significant\* at the 0.05 level of significance at n-2 degrees of freedom (n=26)  The correlations of trap catches with weather parameters were performed through using weather parameters of MCRS with G1-Olpad & for other ginneries with weather parameters of RCRS, Bharuch | | | | | |



**Fig. 8: Correlation of trap catches of male moths at G1- Olpad ginning mill with   
 abiotic factors**



**Fig. 9: Correlation of trap catches of male moths of different ginneries in Bharuch   
 district with abiotic factors**

**3.3 Infestation of pink bollworm in seed cotton at ginneries**

The data on per cent infested seeds out of a total number of seeds observed from January till continuation of ginning processing at fortnight interval in different ginneries are presented in Table 4 which indicated that at Olpad ginning mill, there was <10 per cent infested seeds by the pink bollworm during different periods and the ginning process was completed by the March I fortnight. Similarly, at Hansot ginning mill, the infestation in seeds was below 10 per cent during different fortnights except in January II fortnight and the ginning process was completed by March I fortnight. However, at two private ginning mills (Sikhar & Laheri), the ginning process was continued till April II fortnight and the infestation of pink bollworm to seeds was found >10 per cent during the period of observations at Laheri ginning mill. At Vipul ginning mill, the infestation was more or less above 10 per cent in seeds during different periods and the processing was completed by March II fortnight. The overall infestation to seeds was found 7.41, 9.21, 11.38, 11.62 and 14.79 per cent at Olpad, Hansot, Palej, Karjan and Palej ginneries, respectively.

During ginning process, the outlets of seeds were opened up in the storage yard in open space where the processed seeds from raw seed cotton were piled up at heaps and the samples were collected to check the distribution of infested seeds in different directions in the bottom of the heaps during different periods and the overall data depicted graphically showed (Fig 10) that infested seeds by pink bollworm were found to distribute more in North (13.79% infested seeds) and South (11.96% infested seeds ) than East (9.44% infested seeds) and West (8.67% infested seeds). Within infested seeds, irrespective of locations, the infested single seeds were found more ranging from 56.18 to 68.33 per cent than infested double seeds ranging from 43.05 to 31.67 during different periods of observations and the overall infested single seeds were 60.26 per cent and double seeds was 39.45 per cent (Table 4). Further, the damaged seeds were closely examined for the presence of live larva/pupa and the data indicated that live larva/pupa were recovered more from infested single seeds (8.60 PBW) than in infested double seeds (4.70 PBW) and rest seeds were found damaged but no larva/pupa was observed. The recovery from infested single seeds was found ranging from av. 5.80 to 15.50 live larvae than in infested double seeds ranging from av. 3 to 9 larva/pupa during different periods of observations, irrespective of locations of ginneries.

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| **Fig. 10: Per cent infested seeds by pink bollworm after ginning of raw seed cotton at five ginneries**  **Table 4: Pink bollworm infestation at different ginneries in South Gujarat (2022)** | | | | | | | | | | |
| **Parameters** | **Ginning**  **Mill** | **Infestation of pink bollworm in seeds during ginning process at fortnight interval** | | | | | | | | |
| **January** | | **February** | | **March** | | **April** | | **Overall** |
| I | II | I | **II** | **I** | **II** | **I** | **II** |  |
| Number of total seeds observed | G1 | 466 | 476 | 526 | 493 | 407 | - | - | - | **473.6** |
| G2 | 465 | 457 | 472 | 473 | 434 | - | - | - | **460.2** |
| G3 | 442 | 483 | 467 | 493 | 514 | 443 | 477 | 520 | **479.9** |
| G4 | 450 | 511 | 475 | 451 | 468 | 462 | 464 | 503 | **473.0** |
| G5 | 476 | 464 | 503 | 465 | 471 | 517 | - | - | **482.7** |
|  | **459.8** | **478.2** | **488.6** | **475.0** | **458.8** | **474.0** | **470.5** | **511.5** | **473.9** |
| Number of infested seeds | G1 | 23 | 36 | 36 | 45 | 35 | - | - | - | **35.00** |
| G2 | 37 | 51 | 47 | 40 | 37 | - | - | - | **42.40** |
| G3 | 47 | 54 | 46 | 74 | 80 | 39 | 54 | 45 | **54.90** |
| G4 | 48 | 62 | 71 | 46 | 94 | 87 | 74 | 78 | **70.00** |
| G5 | 46 | 47 | 47 | 74 | 45 | 78 | - | - | **56.20** |
|  | **40.20** | **50.00** | **49.40** | **55.80** | **58.20** | **68.00** | **64.00** | **61.50** | **51.69** |
| Infested seed (%) | G1 | 4.94 | 7.56 | 6.84 | 9.13 | 8.60 | - | - | - | **7.41** |
| G2 | 7.96 | 11.16 | 9.96 | 8.46 | 8.53 | - | - | - | **9.21** |
| G3 | 10.63 | 11.18 | 9.85 | 15.01 | 15.56 | 8.80 | 11.32 | 8.65 | **11.38** |
| G4 | 10.67 | 12.13 | 14.95 | 10.20 | 20.09 | 18.83 | 15.95 | 15.51 | **14.79** |
| G5 | 9.66 | 10.13 | 9.34 | 15.91 | 9.55 | 15.09 | - | - | **11.62** |
|  | **8.77** | **10.43** | **10.19** | **11.74** | **12.47** | **14.24** | **13.63** | **12.08** | **10.88** |
| Infested Single Seeds (%) | G1 | 56.52 | 52.78 | 61.11 | 60.00 | 60.00 | - | - | - | **58.08** |
| G2 | 59.46 | 64.71 | 63.83 | 67.50 | 62.16 | - | - | - | **63.53** |
| G3 | 72.34 | 46.30 | 28.26 | 55.41 | 41.25 | 69.23 | 68.52 | 57.78 | **54.89** |
| G4 | 70.83 | 59.68 | 54.93 | 54.35 | 67.02 | 67.82 | 58.11 | 58.97 | **61.46** |
| G5 | 52.17 | 57.45 | 76.60 | 63.51 | 62.22 | 67.95 | - | - | **63.32** |
|  | **62.27** | **56.18** | **56.95** | **60.15** | **58.53** | **68.33** | **63.31** | **58.38** | **60.26** |
| Infested double seeds (%) | G1 | 43.48 | 41.67 | 38.89 | 37.78 | 40.00 | - | - | - | **40.36** |
| G2 | 40.54 | 33.33 | 36.17 | 35.00 | 37.84 | - | - | - | **36.58** |
| G3 | 27.66 | 53.70 | 71.74 | 44.59 | 58.75 | 30.77 | 31.48 | 42.22 | **45.11** |
| G4 | 29.17 | 40.32 | 45.07 | 45.65 | 32.98 | 32.18 | 41.89 | 41.03 | **38.54** |
| G5 | 47.83 | 42.55 | 23.40 | 36.49 | 37.78 | 32.05 | - | - | **36.68** |
|  | **37.73** | **42.32** | **43.05** | **39.90** | **41.47** | **31.67** | **36.69** | **41.62** | **39.45** |
| Infested single seeds with live larvae | G1 | 3.00 | 4.00 | 3.00 | 4.00 | 2.00 | - | - | - | **3.20** |
| G2 | 7.00 | 10.00 | 7.00 | 9.00 | 8.00 | - | - | - | **8.20** |
| G3 | 10.00 | 7.00 | 1.00 | 18.00 | 9.00 | 7.00 | 12.00 | 8.00 | **9.00** |
| G4 | 4.00 | 14.00 | 9.00 | 4.00 | 25.00 | 24.00 | 19.00 | 15.00 | **14.30** |
| G5 | 8.00 | 6.00 | 9.00 | 12.00 | 5.00 | 10.00 | - | - | **8.30** |
|  | **6.40** | **8.20** | **5.80** | **9.40** | **9.80** | **13.70** | **15.50** | **11.50** | **8.60** |
| Infested Double seeds with live larvae | G1 | 3.00 | 4.00 | 3.00 | 4.00 | 2.00 | - | - | - | **3.20** |
| G2 | 2.00 | 4.00 | 4.00 | 2.00 | 0.00 | - | - | - | **2.40** |
| G3 | 2.00 | 7.00 | 9.00 | 10.00 | 14.00 | 5.00 | 11.00 | 4.00 | **7.80** |
| G4 | 4.00 | 4.00 | 11.00 | 2.00 | 10.00 | 7.00 | 7.00 | 6.00 | **6.40** |
| G5 | 4.00 | 6.00 | 1.00 | 4.00 | 4.00 | 4.00 | - | - | **3.80** |
|  | **3.00** | **5.00** | **5.60** | **4.40** | **6.00** | **5.30** | **9.00** | **5.00** | **4.70** |
| Note: G1- Olpad, G2- Hansot, G3- Sikhar, Palej G4- Laheri, Palej, G5- Vipul, Karjan Ginning mills | | | | | | | | | | |

**Discussion**

The use of pheromone traps for monitoring and decision-making was advocated earlier by Singh and Lather (1989) and Suresh (2001) who opined that the activity of pink bollworm moth can be monitored by pheromone traps which helped to know catches of male moths and the increase in number of trap catches aided to develop the strategies for management. During cotton season, the effectiveness of pheromone traps and lures of pink bollworm for monitoring was successfully demonstrated (Patil et al. 2007; Ahmad and Sarwar, 2013, Yalawar and Patil, 2019) and the male moth trap catches were also aided to predict larval infestation of pink bollworm (*P. gossypiella*), in cotton fields (Staten and Walters, 2021).

Earlier, while studying behavior of pink bollworm in stored cotton seed, Patel and Talati (1972) noticed very low incidence of larval carry over through cotton seeds and other cotton waste material in ginneries. Beltran and Garcia (1983) found that the larvae could survived in infested seeds undergoing diapauses lasting from 73 to 310 days which was broken when the larvae were exposed to high humidity (>85%) and moth emergence started. Sidhu and Dhawan (1985) found emergence of adults from the seed cotton regularly from the cotton ginning and pressing mills and from local cotton mills too. Swami (1999) recorded trap catches to be varied from 3 to 248 per trap, indicating that damaged seed cotton in ginning mills and discarded damaged seeds are the primary sources to carry over. Swami and Rao (2000) reported that adults were continuously emerging in the local ginning mills from the seed cotton received regularly from different regions of the state and also noticed that damaged and discarded kapas, lint and seed in ginning mills were found as the major sources for regular build-up of pink bollworm population. Hanchinal et al. (2018) opined that long-term storage of raw cotton in ginning mills and market yards served as a source of pink bollworms to the ensuing crop. Kumar et al. (2020) opined that the spread of resistant pink bollworm in the North zone on BG II cotton due to transport of resistant larvae along with cotton seeds procured from Central/South zone by the ginneries. ICAR-CICR has suggested installing pheromone traps at all market yards and ginneries to catch any suicidal outbursts, as well as near go-downs, ginning mills, market yards, storage rooms, and other sites where post-season moths may congregate (Anon. 2019 and Anon. 2023).

Further, in present study at Research farm, NAU, Surat the trap catches were found to increase from September and showed peak in December (145 moths/trap/week) whereas in ginneries peak catches were observed in 6th to 8th SMW i.e., February month (10 to 14 male moths/trap). Across ginneries, there was variation in period of activity as well as a number of overall male moths trapped. This might be due to the level of infestation to the raw seed cotton from fields, seeds storage period after processing and prevalent weather with which life cycle fluctuated. It has been observed that the supply of seed cotton in ginneries was initiated from October (after Diwali) and ginning process started at the end of November or December depending on the collection of stock of raw seed cotton. Further, during personal interactions, it was also noticed that the stored raw seed cotton by the traders of previous season was also received in some of the private ginneries and processed in the ginning factory. The ginning processing was observed to be continued till March I fortnight in Co-operative ginning mills (Olpad and Hansot) where overall infested seeds were <10 per cent and at private ginning mills where processing continued till March II or April II fortnights (Palej and Karjan) where overall infested seeds were >10 per cent.

While studying dynamics, Khuhro et al. (2015) recorded a subsequent increase of average maximum trap catches of male moths from 2009 to 2013 recording 4.90 in October 2009, 5.28 in September 2010, 4.01 in November 2011, 5.39 in November 2012 and 7.67 and 6.74 male moths/trap in October and November 2013. Further they observed catches up to March as well as in few years till June too. Sandhyarani et al. (2010) found that the catches of male moths on cotton started from September with a peak during 2nd fortnight of December (52nd standard week) and again from last week of January to first fortnight of February. Nasir et al. (2021) found maximum mean moths catch were observed in traps installed near cotton sticks heaps (av. 85.61 moth catches/trap/site) followed by cotton field (av. 24.47 moth catches/trap/site), factory (av. 6.47 moth catches/trap/site) and seed store (av. 1.22 moth catches/trap/site). Ibrahim et al. (2022) stated that long-term storage of raw cotton in market yards and ginning mills provides a source of pink bollworms for the subsequent crop and opined that pre-harvest awareness and training for clean picking and seasonal and post- harvest installation of pheromone and light traps in fields, close to go-downs, ginning mills, and market yards aided in catches post-season moths and preventing carry over to next season. Ali et al. (2016) found highest peaks during April registering 1.10 and 1.13 moths/trap at 37.78 ˚C and 36.78 ˚C (maximum temperature), 22.00 and 20.12 ˚C (minimum temperature), 29.89 ˚C and 28.46 ˚C (average temperature) and 67 per cent (RH) during 2009 and 2011, respectively whereas peak appeared in November and December during 2010. Further they reported that maximum temperature and rainfall showed positive response while minimum temperature, average temperature and relative humidity had a negative impact on the population fluctuation. Jha and Bisen (1994) studied the effect of climatic factors on the pink bollworm showing progressively increase in incidence over years and reported that maximum (35 ± 10 ˚C) and minimum (25 ± 10 ˚C) temperature combined with high relative humidity (72 ± 5 %) found favorable for its multiplication. Singh and Lather (1989) found that pink bollworm moths remained active throughout the year with minimum intensity during the summer (May and June) and winter (January and February) and the most active period of moth emergence from the larvae of long cycle brood started as early as March and continued as late as mid-July, with maximum emergence between mid-March to April end, when the mean fluctuating temperature ranged between 22.0˚C (March) to 26.5˚C (April). Nasir et al. (2021) found maximum trap catches at cotton sticks heap sites and the moths catch in traps installed near cotton sticks heaps site has positive correlation with mean maximum and minimum temperature while has non-significant correlation with relative humidity and rainfall. Cotton sticks heaps are the major harboring sites of PBW infestation to the successive cotton crop.

4. Conclusion

Moths of pink bollworm were active throughout the year (January to December 2022) at Research farm, MCRS, NAU, Surat and the trap catches were observed low from May to September months indicating proper management reduce the next season initial infestation. In different ginneries of Surat and Bharuch district, the activity of male moths noticed from January to third week of April at ginning mill located at Olpad (Surat district) and Hansot (Bharuch district), whereas the activity was noticed till May end or initial week of June at other three ginneries located at Palej and Karjan (Bharuch district). The peak activity in ginneries was noticed in 7th-8th SMW with peak trap catches of 10 to 14 moths/trap in different ginneries. The continuation of ginning till availability of storage and stock affects infestation to seeds and percentage of single and double seeds within infested seeds and ultimately the emergence of moths. In single seeds, small live larvae whereas resting larvae for short periods were noticed in double seeds. The post-harvest monitoring in the field as well as ginneries and management though mass trapping in ginneries in hot spot area played crucial role in preventing carry over source and spread.

Disclaimer (Artificial intelligence)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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APPENDIX

**Appendix I: Weekly meteorological data recorded at observatory of Main Cotton Research Station, NAU, Surat (2021-22)**

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Months | STD  Week | Period | Weather parameter | | | | | | | |
| Temperature (˚C) | | Relative Humidity (%) | | Sunshine hour | Rain fall (mm) | Rainy days | Wind speed (Km/hr) |
| Maximum | Minimum | Morning | Evening |
| December 2021 | 52 | 24/12/2021 | 27.8 | 17.5 | 84.0 | 62.0 | 5.7 | 0.0 | 0 | 6.7 |
| January 2022 | 1 | 01/01/2022 | 30.6 | 19.7 | 86.0 | 44.0 | 4.2 | 0.0 | 0 | 5.1 |
| 2 | 08/01/2022 | 26.4 | 15.3 | 74.0 | 33.0 | 7.1 | 0.0 | 0 | 8.7 |
| 3 | 15/01/2022 | 30.2 | 17.6 | 83.0 | 34.0 | 7.2 | 0.0 | 0 | 6.0 |
| 4 | 22/01/2022 | 26.4 | 15.2 | 67.0 | 27.0 | 7.4 | 0.0 | 0 | 7.2 |
| 5 | 29/01/2022 | 30.3 | 15.5 | 89.0 | 21.0 | 8.6 | 0.0 | 0 | 3.9 |
| February 2022 | 6 | 05/02/2022 | 30.8 | 16.2 | 84.0 | 28.0 | 8.5 | 0.0 | 0 | 6.1 |
| 7 | 12/02/2022 | 31.5 | 18.1 | 87.0 | 28.0 | 8.0 | 0.0 | 0 | 3.8 |
| 8 | 19/02/2022 | 33.1 | 17.5 | 88.0 | 22.0 | 9.2 | 0.0 | 0 | 4.4 |
| 9 | 26/02/2022 | 34.7 | 20.4 | 68.0 | 21.0 | 8.9 | 0.0 | 0 | 6.8 |
| March 2022 | 10 | 05/03/2022 | 36.4 | 22.8 | 58.0 | 25.0 | 6.4 | 0.0 | 0 | 5.7 |
| 11 | 12/03/2022 | 38.1 | 22.7 | 56.0 | 17.0 | 9.6 | 0.0 | 0 | 5.6 |
| 12 | 19/03/2022 | 36.2 | 24.7 | 68.0 | 20.0 | 6.3 | 0.0 | 0 | 6.2 |
| 13 | 26/03/2022 | 31.1 | 20.7 | 97.0 | 43.0 | 6.6 | 0.0 | 0 | 4.9 |
| April 2022 | 14 | 02/04/2022 | 35.3 | 24.5 | 97.0 | 48.0 | 5.7 | 0.0 | 0 | 4.8 |
| 15 | 09/04/2022 | 35.5 | 26.0 | 94.0 | 41.0 | 5.3 | 0.0 | 0 | 5.8 |
| 16 | 16/04/2022 | 35.9 | 25.8 | 89.0 | 37.0 | 5.5 | 0.0 | 0 | 5.4 |
| 17 | 23/04/2022 | 38.6 | 25.7 | 84.0 | 23.0 | 5.0 | 0.0 | 0 | 5.1 |
| 18 | 30/04/2022 | 34.9 | 27.8 | 90.0 | 52.0 | 5.4 | 0.0 | 0 | 6.6 |
| May 2022 | 19 | 07/05/2022 | 37.0 | 28.2 | 89.0 | 40.0 | 3.4 | 0.0 | 0 | 7.3 |
| 20 | 14/05/2022 | 34.4 | 28.8 | 86.0 | 57.0 | 3.5 | 0.0 | 0 | 8.7 |
| 21 | 21/05/2022 | 33.9 | 29.1 | 81.0 | 58.0 | 3.1 | 0.0 | 0 | 11.1 |
| 22 | 28/05/2022 | 34.6 | 28.9 | 83.0 | 53.0 | 2.8 | 0.0 | 0 | 8.8 |
| June 2022 | 23 | 04/06/2022 | 35.0 | 28.9 | 85.0 | 55.0 | 3.1 | 0.0 | 0 | 8.4 |
| 24 | 11/06/2022 | 33.4 | 27.7 | 91.0 | 64.0 | 3.8 | 49.0 | 2 | 7.0 |
| 25 | 18/06/2022 | 32.5 | 25.9 | 96.0 | 73.0 | 2.8 | 91.0 | 6 | 5.2 |
| 26 | 25/06/2022 | 32.8 | 26.6 | 96.0 | 72.0 | 1.9 | 96.0 | 5 | 5.4 |
| July 2022 | 27 | 02/07/2022 | 30.5 | 25.6 | 99.0 | 83.0 | 1.0 | 275.5 | 7 | 5.9 |
| 28 | 09/07/2022 | 28.9 | 25.5 | 100.0 | 88.0 | 0.0 | 221.5 | 7 | 7.2 |
| 29 | 16/07/2022 | 30.9 | 26.5 | 95.0 | 77.0 | 2.0 | 30.5 | 6 | 7.0 |
| 30 | 23/07/2022 | 31.9 | 26.2 | 95.0 | 68.0 | 2.3 | 37.5 | 5 | 6.4 |

**Appendix I: Weekly meteorological data recorded at observatory of Main Cotton Research Station, NAU, Surat (2021-22) continue**

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Months | STD  Week | Period | Weather parameter | | | | | | | |
| Temperature (˚C) | | Relative Humidity (%) | | Sunshine hour | Rain fall (mm) | Rainy days | Wind speed (Km/hr) |
| Maximum | Minimum | Morning | Evening |
|  | 31 | 30/07/2022 | 33.1 | 26.9 | 90.0 | 63.0 | 3.7 | 84.0 | 2 | 5.8 |
| August 2022 | 32 | 06/08/2022 | 31.4 | 26.0 | 90.0 | 60.0 | 1.9 | 100.5 | 6 | 6.4 |
| 33 | 13/08/2022 | 29.8 | 25.5 | 88.0 | 60.0 | 2.4 | 218.0 | 7 | 7.7 |
| 34 | 20/08/2022 | 31.2 | 26.9 | 80.0 | 60.0 | 3.4 | 4.5 | 4 | 7.2 |
| 35 | 27/08/2022 | 33.4 | 25.9 | 85.0 | 65.0 | 5.6 | 23.5 | 4 | 4.3 |
| September 2022 | 36 | 03/09/2022 | 34.4 | 26.7 | 84.0 | 61.0 | 4.8 | 16.5 | 3 | 5.0 |
| 37 | 10/09/2022 | 31.5 | 25.3 | 87.0 | 74.0 | 2.0 | 130.5 | 7 | 4.1 |
| 38 | 17/09/2022 | 31.4 | 25.7 | 81.0 | 76.0 | 4.1 | 8.0 | 2 | 4.9 |
| 39 | 24/09/2022 | 32.5 | 25.2 | 81.0 | 67.0 | 5.2 | 27.0 | 3 | 3.9 |
| October 2022 | 40 | 01/10/2022 | 33.4 | 26.3 | 77.0 | 62.0 | 6.7 | 19.5 | 1 | 5.6 |
| 41 | 08/10/2022 | 32.1 | 24.4 | 83.0 | 75.0 | 5.3 | 60.0 | 3 | 4.2 |
| 42 | 15/10/2022 | 34.8 | 23.7 | 63.0 | 50.0 | 6.7 | 0.0 | 0 | 5.1 |
| 43 | 22/10/2022 | 35.2 | 21.0 | 64.0 | 39.0 | 8.9 | 0.0 | 0 | 3.2 |
| 44 | 29/10/2022 | 35.2 | 19.3 | 56.0 | 39.0 | 8.6 | 0.0 | 0 | 3.9 |
| November 2022 | 45 | 05/11/2022 | 35.7 | 20.2 | 63.0 | 49.0 | 7.7 | 0.0 | 0 | 4.8 |
| 46 | 12/11/2022 | 34.0 | 20.7 | 55.0 | 42.0 | 7.3 | 0.0 | 0 | 5.1 |
| 47 | 19/11/2022 | 32.3 | 16.3 | 54.0 | 33.0 | 8.6 | 0.0 | 0 | 3.8 |
| 48 | 26/11/2022 | 33.3 | 18.2 | 58.0 | 45.0 | 7.2 | 0.0 | 0 | 6.4 |
| December 2022 | 49 | 03/12/2022 | 31.7 | 20.5 | 64.0 | 49.0 | 6.7 | 0.0 | 0 | 5.2 |
| 50 | 10/12/2022 | 33.6 | 21.5 | 68.0 | 49.0 | 5.7 | 0.0 | 0 | 5.9 |
| 51 | 17/12/2022 | 32.0 | 20.0 | 62.0 | 42.0 | 9.0 | 0.0 | 0 | 5.0 |
| 52 | 24/12/2022 | 30.1 | 15.0 | 74.0 | 52.0 | 7.9 | 0.0 | 0 | 5.2 |
|  |  | **32.9** | **23.1** | **80.1** | **49.5** | **5.5** | **1493.0** | **80.0** | **5.8** |

**Appendix II: Weekly meteorological data recorded at observatory of Regional Cotton Research Station, NAU, Bharuch (2021-22)**

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Months | Standard weeks | Temperature (˚C) | | Relative humidity (%) | | Rainfall (mm) | Rainy Day | Sunshine hour | Wind speed  (Km/hr) |
| Maximum | Minimum | Morning | Evening |
| December 2021 | 52 | 27.7 | 15.0 | 80.3 | 47.4 | 0.0 | 0.0 | 6.4 | 5.0 |
| January 2022 | 1 | 29.4 | 17.6 | 84.4 | 56.6 | 0.0 | 0.0 | 4.5 | 4.8 |
| 2 | 25.8 | 12.4 | 81.1 | 76.7 | 0.0 | 0.0 | 8.2 | 6.4 |
| 3 | 29.5 | 14.5 | 83.4 | 62.0 | 0.0 | 0.0 | 8.3 | 5.4 |
| 4 | 25.3 | 12.1 | 78.9 | 35.4 | 0.0 | 0.0 | 6.7 | 6.1 |
| 5 | 29.6 | 13.2 | 75.7 | 34.7 | 0.0 | 0.0 | 8.6 | 3.7 |
| February 2022 | 6 | 30.0 | 13.3 | 74.4 | 29.3 | 0.0 | 0.0 | 8.0 | 4.1 |
| 7 | 31.4 | 14.7 | 61.9 | 27.4 | 0.0 | 0.0 | 8.8 | 4.4 |
| 8 | 34.1 | 15.3 | 74.1 | 23.6 | 0.0 | 0.0 | 9.3 | 3.6 |
| 9 | 34.8 | 14.9 | 62.3 | 22.7 | 0.0 | 0.0 | 9.2 | 5.0 |
| March 2022 | 10 | 35.8 | 19.6 | 73.3 | 38.3 | 0.0 | 0.0 | 8.0 | 5.0 |
| 11 | 38.9 | 20.4 | 55.0 | 19.6 | 0.0 | 0.0 | 9.0 | 4.7 |
| 12 | 37.6 | 22.6 | 49.7 | 21.3 | 0.0 | 0.0 | 5.3 | 4.8 |
| 13 | 38.3 | 22.3 | 57.1 | 25.4 | 0.0 | 0.0 | 7.6 | 5.3 |
| April 2022 | 14 | 40.2 | 23.1 | 60.0 | 21.7 | 0.0 | 0.0 | 9.2 | 6.1 |
| 15 | 40.8 | 23.6 | 68.4 | 21.4 | 0.0 | 0.0 | 9.1 | 6.6 |
| 16 | 39.4 | 23.9 | 62.3 | 25.1 | 0.0 | 0.0 | 8.4 | 7.1 |
| 17 | 41.9 | 23.9 | 51.9 | 20.4 | 0.0 | 0.0 | 10.2 | 5.4 |
| 18 | 39.1 | 26.8 | 75.6 | 42.9 | 0.0 | 0.0 | 9.7 | 9.8 |
| May 2022 | 19 | 42.2 | 27.8 | 72.3 | 34.4 | 0.0 | 0.0 | 9.0 | 7.9 |
| 20 | 38.4 | 28.0 | 80.4 | 45.0 | 0.0 | 0.0 | 9.0 | 10.8 |
| 21 | 37.0 | 28.5 | 70.3 | 51.1 | 0.0 | 0.0 | 8.5 | 15.0 |
| 22 | 37.5 | 28.1 | 75.4 | 49.6 | 0.0 | 0.0 | 8.6 | 13.1 |
| June 2022 | 23 | 39.2 | 28.3 | 69.3 | 45.9 | 0.0 | 0.0 | 9.0 | 11.1 |
| 24 | 36.5 | 26.4 | 67.1 | 51.4 | 2.2 | 0.3 | 8.2 | 11.6 |
| 25 | 35.5 | 26.7 | 79.6 | 56.4 | 2.9 | 0.3 | 7.5 | 9.8 |
| 26 | 34.7 | 26.6 | 83.6 | 63.6 | 5.9 | 0.1 | 5.2 | 8.7 |
|  |  | **35.2** | **21.1** | **70.7** | **38.9** | **11.0** | **0.7** | **8.1** | **7.1** |