**Spatio-Temporal Dynamics of Spider Populations in *Bt* and Non-*Bt* Cotton Agroecosystems of South Gujarat, India: Influence of Biotic and Abiotic Factors**

**Abstract:** A field investigation studied the seasonal abundance and activity of spider populations in cotton fields across treatment plots in Surat and Bharuch, Gujarat. In Surat, spider activity in unprotected plots of the *Bt* cotton hybrid RCH 2 BG II was noted from the 29th to the 1st Standard Meteorological Week (SMW), peaking (>0.80 spiders/plant) between the 46th (second week of November) and 51st SMW (third week of December). In protected plots of the same hybrid, spiders were active from the 31st to the 1st SMW, with peak densities observed from the 46th to 1st SMW (first week of January). Similarly, in non-transgenic Suraj variety, unprotected plots showed spider activity from the 29th to the 1st SMW, peaking from the 41st to 51st SMW. In Bharuch, spider activity spanned from the 32nd to the 52nd SMW in all plots. In unprotected plots of RCH 2 BG II, peak spider activity (>0.80 spiders/plant) occurred from the 44th (fourth week of October) to the 52nd SMW. Protected plots of the same hybrid peaked from the 47th to the 52nd SMW. In Suraj, unprotected plots peaked from the 44th (fifth week of October) to the 52nd SMW, while protected plots peaked from the 46th to the 52nd SMW. Positive correlations were found between spider populations and pest species like aphids, jassids, whiteflies, and mealybugs, as well as abiotic factors such as maximum temperature and sunshine hours in Surat. In contrast, significant negative correlations were noted with morning and evening relative humidity, rainfall, and rainy days. At Bharuch, spider populations positively correlated with aphids, whiteflies, mealybugs, and sunshine hours, while negatively correlating with minimum temperature, relative humidity, and rainy days.

**Key words:** Spider, correlation, biotic factors, abiotic factors, transgenic, non-transgenic

1. **INTRODUCTION**

Cotton (*Gossypium hirsutum* L.), a member of the Family Malvaceae and Order Malvales, is one of the most important commercial crops in the world, with significant economic, political and social impact. The word "cotton" is derived from the Arabic word “quotn” (Lee and Fang, 2015) and is associated with the *Gossypium* variety, which also comes from the Arabic term “goz” (Gledhill, 2008), meaning a soft material. Cotton is a soft, delicate staple fiber that grows in a boll or protective capsule surrounding the seeds of plants (Cobley, 1956).

Spiders (Arachnida: Araneae) are a highly diverse group of invertebrates that can regulate the terrestrial arthropod population (Coddington and Levi, 1991) and occupy agricultural habitats (Wise, 1993; Nyffeler, 2000). As generalist predators, spiders have great ecological importance, occupying the top food chain of invertebrates and displaying remarkable diversity and abundance. They can be exploited for their biocontrol potential in controlling insect pests in agricultural ecosystems. Spider communities in various natural environments can play a significant role in controlling the populations of harmful arthropods (Ghafoor, 2002). Spiders possess unique characteristics, viz., being able to kill large numbers of insects per unit of time, good searching ability, a wide host range, adaptation under food constraints, a low metabolic rate, ease in multiplication, polyphagous and equipped with an energy conservation mechanism. The world list of spiders includes 52,835 species under 4,427 genera and 136 families. India has over 1,700 species belonging to 450 genera under 61 families (Anon., 2025- WSC). Spiders have been observed as potential natural enemies of key cotton pests and play an important role in the cotton ecosystem, too (Dhaka *et al*., 2007).

In his classic work "On the Origin of Species," published in 1859, Charles Darwin was the first to propose the idea that an organism's environment is made up of various components that can independently or collectively affect the animal's ability to survive and reproduce. Biotic and abiotic factors play a significant role in determining the distribution of species over time and space (Yazdani and Agarwal, 1997). The influence of abiotic factors, especially climate, on the reproduction, development and survival of insects at both the individual and population level has been well established. However, understanding the impact of the interactions between these factors has been a longstanding challenge for ecologists. In order to get better understanding of spider variations in the spider populations during crop growth, sound knowledge on the factors influencing spider community structure was essential for future studies on the arthropod fauna. Hence, the research project “Diversity of spiders (Arachnida: Araneae) in cotton fields of Surat and Bharuch districts of south Gujarat” was undertaken at the Main Cotton Research Station, NAU, Surat and Regional Cotton Research Station, NAU, Bharuch, as well as farmer’s fields during 2023-24 and 2024-25

**2. MATERIALS AND METHODS**

The incidence of spiders was recorded in protected and unprotected plots of *Bt* cotton hybrid (RCH 2 BG II) and Non *Bt* variety (Suraj) throughout the *Kharif* season at one-week interval during 2023-24 and 2024-25.

**Table 1. Experimental detail**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Research farms** | |  | **MCRS, Surat** | | **RCRS, Bharuch** |
| Year | | : | 2023-24 and 2024-25 | | 2023-24 and 2024-25 |
| Location | | : | Research farm, Ento | | Research Farm, Ento |
| Season | | : | *Kharif* | | *Kharif* |
| Crop | | : | Cotton  *Gossypium hirsutum* | | Cotton  *Gossypium hirsutum* |
| Spacing | | : | 1.20x0.45m | | 1.20x0.45 m |
| Seed rate | | : | 2.5 kg/ha | | 2.5 kg/ha |
| Samples | | : | 40 | | 40 |
| Treatment | | : | ***Bt***: RCH 2 BG II   1. Protected block 2. Unprotected block for sucking pests & PBW   **Non-*Bt***: Suraj   1. Protected block 2. Unprotected block for sucking pests & Bollworms | | ***Bt***: Rasi 2 BG II  A. Protected block  B. Unprotected block for  sucking pests &  PBW  **Non-*Bt***: Suraj   1. Protected block 2. Unprotected block for sucking pests & Bollworms |
| Block size: | | : | Each 500 sq. m  Total: 2000 sq. m | | Each 500 sq. m  Total: 2000 sq. m |
| Distance between blocks | | : | 6 m | | 6 m |
| Sowing date | | : | 1st year: 29/06/2023  2nd year: 03/07/2024 | | 1st year: 08/07/2023  2nd year: 04/07/2024 |
| Design | | : | Large plot technique | | Large plot technique |
| Manure and Fertilizer | | : | 10t FYM /ha and  240-40-0 NPK Kg/ha | | 10t FYM /ha and  240-40-0 NPK Kg/ha |
| Weeding and inter-culturing | |  | Pre-emergence spray of Pendimethalin and three hand weeding and two inter-culturing with tractor | | Pre-emergence spray of Pendimethalin and three hand weeding and two inter-culturing with a tractor |
| Irrigation | | : | One month after cessation of rain | | NIL |
| Plant Protection Measures  (Appendix 1) | | : | * ETL based sprays for sucking pests and bollworms in protected block * Kept unsprayed   throughout the crop period for sucking pests and bollworms in unprotected block of *Bt* and Non *Bt* | | * ETL based sprays for sucking pests and bollworms in protected block * Kept unsprayed throughout the crop period for bollworms in an unprotected block of *Bt* and non-*Bt* |
| Date of crop termination | | : | 1st year: 02/01/2024  2nd year:16/01/2025 | | 1st year: 07/01/2024  2nd year:11/01/2025 |
| **List of target insects** | | | | **Purpose** | | |
| 1 | Collection & Occurrence of spiders | | | Collection of spiders and Monitoring of the occurrence of spiders in relation to biotic and abiotic factors | |
| 2 | Incidence of spiders | | |
| 3 | Incidence of sucking pests and bollworms | | |

**Plant Protection Measures:**

To ascertain the correct diversity of the spider species as well as their occurrence in the cotton crops at two districts, besides farmers’ fields’, attempt was also made to collect different species of spiders and to record the occurrence of spiders (total populations) from protected and unprotected fixed plots of *Bt* hybrid (RCH 2 BG II) and non-*Bt* variety (Suraj) during *Kharif* seasons of 2023-24 and 2024-25. In all protected plots, recommended ETL-based interventions for sucking pests and bollworms (only pink bollworm in the case of *Bt* hybrid) were implemented in both *Bt* cotton hybrid and non-*Bt* variety. For sucking pests, both *Bt* and non-*Bt* cotton plots were treated with the same set of insecticides *viz*., Flonicamid 50 WG, Thiamethoxam 25 WG, Buprofezin 25 SC, and Dimethoate 30 EC. These insecticides target major sucking pests, including aphids, jassids, whiteflies, and thrips. In *Bt* cotton hybrid (RCH 2 BG II), which possesses inherent resistance to bollworms, an additional insecticide, Emamectin benzoate 5 SG, was specifically applied only for the management of pink bollworm (*Pectinophora gossypiella*) in case of outbreak or infestation. In non-*Bt* cotton (Suraj), which lacks genetic resistance to bollworm species, a broader chemical control strategy was implemented for all types of bollworms. The insecticides used included Chlorpyriphos 20 EC, Quinalphos 25 EC, and Indoxacarb 14.5 SC, ensuring effective control of pink, spotted, and American bollworms.

**Method of recording observations**:

The incidence of cotton pests and spiders was studied by recording periodic counts of spiders, sucking pests, bollworms and their damage. The interventions for management of specific insect pests were followed based on Economic Threshold Levels in protected plots only. The methodology for recording insect pests is described as under.

The occurrence of spiders (nymphs and adults) was recorded from five randomly selected plants from each plot. The nymphs and adults of aphid, thrips and whitefly were recorded on five randomly selected plants on three leaves selected from top, middle and bottom canopy of the plants from each plot. Population counts of mealy bugs (crawlers and adult stages) were recorded from 5 cm apical shoot length of five tagged plants at weekly interval. The ETL of sucking pests viz. leaf hopper (av. 2 leafhoppers/leaf), thrips, aphids and whitefly (av. 10 insects/ leaf) and for mealybug (av. 2 grades /plant) were followed for interventions in protected plots. The populations of sucking pests were recorded at standard week intervals during morning hours, starting after germination till the maturity of the crop. The incidence of mite was not noticed in any of the plots.

The number of healthy and damage flowers by larvae of pink bollworm from five randomly selected plants were counted at 15-day interval starting from 45 days after sowing (DAS) till 120 DAS in each plot. Similarly, Green boll damage and locule damage was recorded by destructive sampling of 20 green bolls from 90 to 150 DAS from each plot. At harvest, the damage to open bolls and locules by pink bollworm was recorded by counting the number of healthy and damaged open bolls and locules by the pink bollworm separately from five plants from each plot. The number of damaged squares were counted based on number of healthy and damaged squares by spotted bollworm and American bollworm separately from five randomly selected plants from each plots during squaring time at one-week interval (75 to 120 DAS). Similarly, number of healthy and damage green bolls were also counted from five randomly selected plants in each of the treatment combinations during fruiting periods at one-week interval (90 to 135 DAS). At the harvest, damage to open bolls and locules by larvae of spotted and American bollworm was also recorded by counting the number of healthy and damaged open bolls and locules by the spotted and American bollworm separately from five plants in each plot. The above data were converted to per cent damage to squares. green bolls, open bolls and locules for both the bollworms. The number of larvae of spotted and American bollworm was also recorded on 5 randomly selected plants during its period of occurrence at one-week interval in all the treatment combinations. The ETL for pink bollworm is 5-10 % fruiting body damage or1- 2 larvae per 20 bolls (rosette flower, green bolls, or open bolls) while for spotted and American bollworm is > 20 % fruiting body damage (Square, green bolls or open bolls) or >2 larvae/plant. The unprotected plots were kept free from insecticidal application.

|  |  |  |  |
| --- | --- | --- | --- |
| Percent  Boll  Damage  (%) |  | Total Number of Bolls Examined | ×100 |
| = | Number of  Damaged Bolls |

The comparative studies of spider incidence in protected and unprotected plots of *Bt* hybrid and Non *Bt* variety were tested through paired t test and interpreted while the occurrence / abundance of spiders in relation to biotic and abiotic factors were studied using the data of spider incidence and their prey insects from unprotected plots of *Bt* cotton hybrid (majority of area of cultivation is *Bt* cotton hybrid) as well as data on weather parameters recorded at observatories of respective locations. The correlation between spiders and biotic factors, viz., soft-bodied insects (sucking pests and larvae of bollworms), was also studied, along with their significance through the ‘t’ test.

|  |  |  |
| --- | --- | --- |
| t | = | dˉ​̄ |
| sd/√n |

Where:

dˉ = mean of the differences

sd​ = standard deviation of the differences

n = number of paired observations

For studying the correlations of spider incidence with abiotic factors weather data *viz.*, maximum temperature (0C), minimum temperature (0C), average temperature (0C), morning relative humidity (%), evening relative humidity (%), average relative humidity (%), wind speed (km/hr.), sunshine hours, evaporation (mm), rainfall (mm) and rainy days recorded as per Standard Meteorological Week (SMW) at Meteorological observatories at Main Cotton Research Station, Surat and Regional Cotton Research Station, Navsari Agricultural University, Maktampur, Bharuch were obtained and used for the present study.

1. **RESULTS AND DISCUSSION**

The occurrence of spiders was recorded in protected and unprotected blocks of RCH 2 BG II and Suraj (Non-*Bt* variety) throughout the *Kharif* season at one-week intervals during 2023-24 and 2024-25.

**3.1 Occurrence of spiders was recorded in protected and unprotected blocks of RCH 2 BG II and Suraj (Non-*Bt* variety)**

**Main Cotton Research Station, Surat**

The data on the occurrence of spiders in protected and unprotected plots of RCH 2 BG II (*Bt* cotton hybrid) and Suraj (non-*Bt* variety) recorded during *Kharif* 2023 and 2024 are presented in Table 2.

In 2023, the incidence of spider was found to have initiated from the 29th Standard Meteorological Week (SMW) till 1st SMW showing peak population (1.08 spiders/plant) in the 46th SMW in unprotected plot of RCH 2 BG II. In 2024, more or less similar trend was noticed, incidence being initiated from the 29th SMW till crop end with peak population (1.20 spiders/plant) in 49th SMW. The pooled data of two years revealed that spiders were active from the 29th to 1st SMW, with their peak activity (>0.80 spider/plant) was found from the 46th (second week of November) to 51st (third week of December) SMW in unprotected plots of RCH 2 BG II. In protected plot of RCH 2 BG II the incidence of spider was found initiated from the 31st SMW till crop end showing peak population (1 spider/plant) in the 47th and 51st SMW in 2023.Whereas in 2024, the incidence was initiated from the 31st SMW with peak population in 1st SMW in protected plot of RCH 2 BG II. The pooled data of two years revealed that spiders were active from the 31st to 1st SMW, with their peak activity (>0.80 spider/plant) was found from the 46th (second week of November) to the 1st SMW(first week of January) SMW in protected plots of RCH 2 BG II.

Attempt was also made to study the occurrence of spiders in unprotected and protected plots of Suraj (non–transgenic variety). In 2023, the incidence of spider was found initiated from the 29th Standard Meteorological Week (SMW) till 1st SMW showing peak population (1.08 spiders/plant) in the 46th SMW in unprotected plot of Suraj. In 2024, more or less similar trend was noticed, incidence being initiated from the 29th SMW till crop end with peak population (1.24 spiders/plant) in 50th SMW. The pooled data of two years revealed that spiders were active from the 29th to 1st SMW, with their peak activity (>0.80 spider/plant) was found from the 41st (second week of November) to 51st (third week of December) SMW in unprotected plots of Suraj. In protected plot of Suraj the incidence of spider was found initiated from the 31st SMW till crop end showing peak population (1 spider/plant) in the 45th, 47th and 52nd SMW in 2023. Whereas in 2024, the incidence was initiated from the 31st SMW with peak population in 1st SMW in protected plot of Suraj. The pooled data of two years revealed that spiders were active from the 31st to 1st SMW, with their peak activity (>0.80 spider/plant) was found from the 43rd (first week of November) to the 1st SMW(first week of January) SMW in protected plot of Suraj.

**Regional Cotton Research Station, Bharuch**

The data on the occurrence of spiders in protected and unprotected plots of RCH 2 BG II (*Bt* cotton hybrid) and Suraj (non-*Bt* variety) recorded during *Kharif* 2023 and 2024 are presented in Table 3. In 2023, the incidence of spider was found initiated from the 32nd SMW till 52nd SMW showing peak population (1.04 spiders/plant) in the 48th SMW in unprotected plot of RCH 2 BG II. In 2024, more or less similar trend was noticed, incidence being initiated from the 32nd SMW till crop end with peak population (1.24 spiders/plant) in 52nd SMW. The pooled data of two years revealed that spiders were active from the 32nd to 52nd SMW, with their peak activity (>0.80 spider/plant) was found from the 44th (fourth week of October) to 52nd (fourth week of December) SMW in unprotected plots of RCH 2 BG II. In protected plot of RCH 2 BG II the incidence of spider was found initiated from the 32nd SMW till crop end showing peak population (0.92 spider/plant) in the 50th SMW in 2023.Whereas in 2024, the incidence was initiated from the 32nd SMW with peak population in 50th SMW in protected plot of RCH 2 BG II. The pooled data of two years revealed that spiders were active from the 32nd to 52nd SMW, with their peak activity (>0.80 spider/plant) was found from the 47th (third week of November) to the 52nd SMW(fourth week of December) SMW in protected plots of RCH 2 BG II.

Attempt was also made to study the occurrence of spiders in unprotected and protected plots of Suraj (non –transgenic variety). In 2023, the incidence of spider was found initiated from the 32nd SMW till 52nd SMW showing peak population (1.04 spiders/plant) in the 49th SMW in unprotected plot of Suraj. In 2024, more or less similar trend was noticed, incidence being initiated from the 32nd SMW till crop end with peak population (1.00 spider/plant) in 47th SMW. The pooled data of two years revealed that spiders were active from the 32nd to 52nd SMW, with their peak activity (>0.80 spider/plant) was found from the 44th (fifth week of October) to 52nd (last week of December) SMW in unprotected plots of Suraj. In protected plot of Suraj the incidence of spider was found initiated from the 32nd SMW till crop end showing peak population (1.04 spiders/plant) in the 50th SMW in 2023.Whereas in 2024, the incidence was initiated from the 32nd SMW with peak population in 49th SMW in protected plot of Suraj. The pooled data of two years revealed that spiders were active from the 32nd to 52nd SMW, with their peak activity (>0.80 spider/plant) was found from the 46th (second week of November) to the 52nd SMW(fourth week of December) SMW in protected plot of Suraj.

Based on the pooled data of two years, the spider population was found to be higher in the unprotected plots of both RCH 2 BG II and Suraj, with a statistically significant difference (t-test) observed between the spider populations in unprotected and protected plots of each variety at both Surat and Bharuch. This may be attributed to greater prey availability and reduced anthropogenic disturbances in unprotected plots, facilitating better survival and foraging opportunities for spiders (Patil *et al*., 2021; Ali *et al*., 2020). Furthermore, the spider population was comparatively higher in the unprotected plot of Suraj than RCH 2 BG II at Surat, while the reverse trend was observed at Bharuch. These contrasting results at irrigated (Surat) and rainfed (Bharuch) locations may be explained by variations in prey density between the *Bt* and non-*Bt* cotton due to local environmental conditions and host plant-pest interactions (Mujahid *et al*., 2020; Gajbe, 1999). Additionally, environmental factors such as irrigation regimes, rainfall variability, and microclimatic differences likely influenced both prey populations and spider activity, thereby affecting the observed predator densities (Bhute *et al*., 2012; Bhat *et al*., 2013).

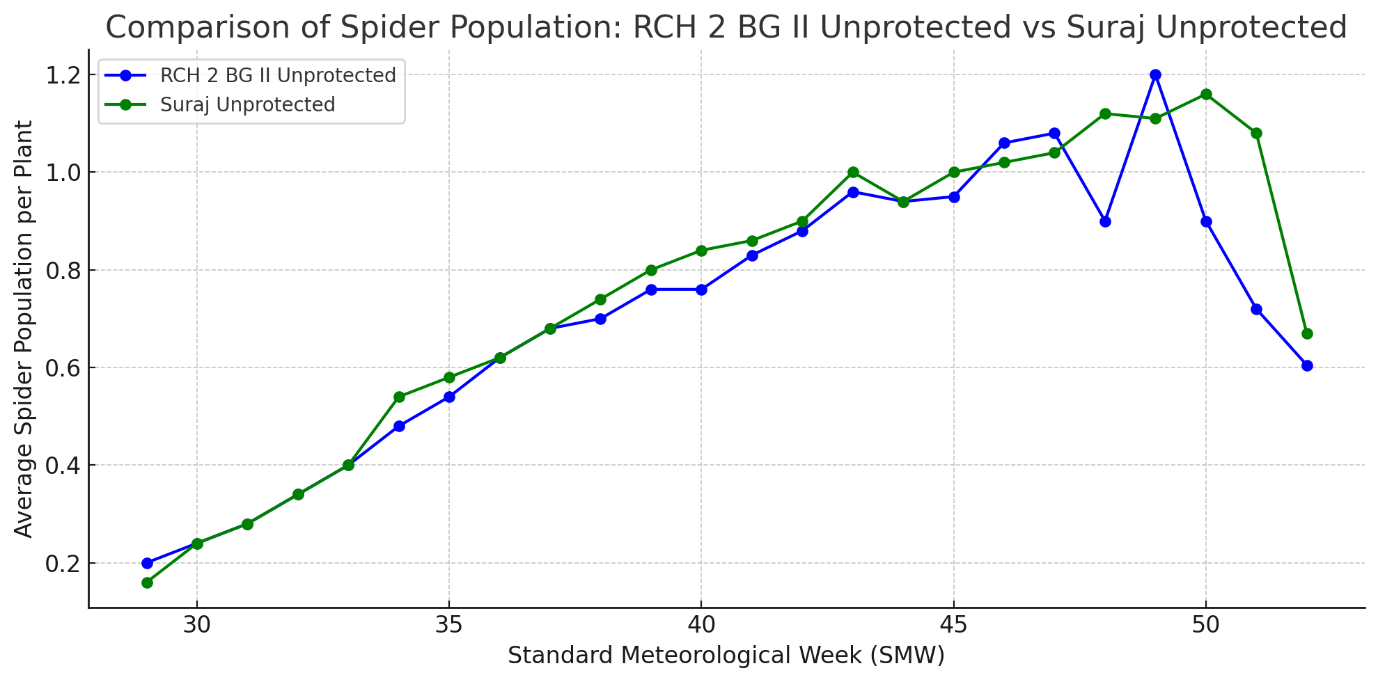
**Table 2: Incidence of spider in cotton fields of RCH 2 BG II and Suraj at MCRS, Surat during *Kharif* 2023-24 and 2024-25**

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **SMW** | **Average number of spiders/plant** | | | | | | | | | | | |
| **Transgenic (RCH 2 BG II)** | | | | | | **Non-transgenic (Suraj)** | | | | | |
| **Protected** | | **Average** | **Unprotected** | | **Average** | **Protected** | | **Average** | **Unprotected** | | **Average** |
| **2023** | **2024** | **2023** | **2024** | **2023** | **2024** | **2023** | **2024** |
| 29 | 0.00 | 0.00 | 0.00 | 0.16 | 0.24 | 0.20 | 0.00 | 0.00 | 0.00 | 0.12 | 0.20 | 0.16 |
| 30 | 0.00 | 0.00 | 0.00 | 0.20 | 0.28 | 0.24 | 0.00 | 0.00 | 0.00 | 0.16 | 0.32 | 0.24 |
| 31 | 0.12 | 0.24 | 0.18 | 0.24 | 0.32 | 0.28 | 0.16 | 0.12 | 0.14 | 0.20 | 0.36 | 0.28 |
| 32 | 0.24 | 0.28 | 0.26 | 0.28 | 0.40 | 0.34 | 0.2 | 0.2 | 0.20 | 0.28 | 0.40 | 0.34 |
| 33 | 0.12 | 0.36 | 0.24 | 0.36 | 0.44 | 0.40 | 0.2 | 0.24 | 0.22 | 0.36 | 0.44 | 0.40 |
| 34 | 0.32 | 0.4 | 0.36 | 0.48 | 0.48 | 0.48 | 0.28 | 0.28 | 0.28 | 0.48 | 0.60 | 0.54 |
| 35 | 0.40 | 0.48 | 0.44 | 0.56 | 0.52 | 0.54 | 0.44 | 0.36 | 0.40 | 0.56 | 0.60 | 0.58 |
| 36 | 0.44 | 0.36 | 0.40 | 0.64 | 0.60 | 0.62 | 0.48 | 0.32 | 0.40 | 0.60 | 0.64 | 0.62 |
| 37 | 0.52 | 0.52 | 0.52 | 0.68 | 0.64 | 0.66 | 0.56 | 0.4 | 0.48 | 0.68 | 0.68 | 0.68 |
| 38 | 0.60 | 0.56 | 0.58 | 0.72 | 0.68 | 0.70 | 0.52 | 0.44 | 0.48 | 0.72 | 0.72 | 0.72 |
| 39 | 0.56 | 0.60 | 0.58 | 0.76 | 0.72 | 0.74 | 0.48 | 0.48 | 0.48 | 0.76 | 0.76 | 0.76 |
| 40 | 0.6 | 0.64 | 0.62 | 0.80 | 0.76 | 0.78 | 0.6 | 0.52 | 0.56 | 0.80 | 0.80 | 0.80 |
| 41 | 0.68 | 0.56 | 0.62 | 0.84 | 0.80 | 0.82 | 0.64 | 0.68 | 0.66 | 0.84 | 0.84 | 0.84 |
| 42 | 0.72 | 0.68 | 0.70 | 0.88 | 0.88 | 0.88 | 0.68 | 0.72 | 0.70 | 0.88 | 0.84 | 0.86 |
| 43 | 0.80 | 0.76 | 0.78 | 0.92 | 0.88 | 0.90 | 0.80 | 0.88 | 0.84 | 0.92 | 0.88 | 0.90 |
| 44 | 0.76 | 0.84 | 0.80 | 0.96 | 0.92 | 0.94 | 0.72 | 0.76 | 0.74 | 0.96 | 0.92 | 0.94 |
| 45 | 0.72 | 0.88 | 0.80 | 1.00 | 0.96 | 0.98 | 1.00 | 1.08 | 1.04 | 1.04 | 0.96 | 1.00 |
| 46 | 0.92 | 0.84 | 0.88 | 1.08 | 1.00 | 1.04 | 0.84 | 0.92 | 0.88 | 1.08 | 1.00 | 1.04 |
| 47 | 1.00 | 0.92 | 0.96 | 1.00 | 1.08 | 1.04 | 1.00 | 1.04 | 1.02 | 1.00 | 1.08 | 1.04 |
| 48 | 0.72 | 0.92 | 0.82 | 0.92 | 1.12 | 1.02 | 0.92 | 0.96 | 0.94 | 0.92 | 1.12 | 1.02 |
| 49 | 0.88 | 0.94 | 0.91 | 0.84 | 1.20 | 1.02 | 0.84 | 0.88 | 0.86 | 0.84 | 1.20 | 1.02 |
| 50 | 0.76 | 0.88 | 0.82 | 0.80 | 1.00 | 0.90 | 0.94 | 0.92 | 0.93 | 0.80 | 1.24 | 1.02 |
| 51 | 1.00 | 0.92 | 0.96 | 0.72 | 0.96 | 0.84 | 0.96 | 0.96 | 0.96 | 0.72 | 1.08 | 0.90 |
| 52 | 0.88 | 0.96 | 0.92 | 0.60 | 0.72 | 0.66 | 1.00 | 1.04 | 1.02 | 0.60 | 0.92 | 0.76 |
| 1 | 0.84 | 1.00 | 0.92 | 0.48 | 0.73 | 0.61 | 0.80 | 1.12 | 0.96 | 0.52 | 0.68 | 0.60 |
| **Mean** | **0.61** | **0.65** | **0.63** | **0.68** | **0.71** | **0.71** | **0.63** | **0.64** | **0.61** | **0.67** | **0.71** | **0.72** |
| **SD** | **0.52** | **0.48** | **0.49** | **0.40** | **0.37** | **0.38** | **0.53** | **0.59** | **0.56** | **0.42** | **0.37** | **0.38** |
|  | | | | | | | | | | | | |
| ‘t’ test | | | SurajUnprotected v/s  Suraj Protected | | | -3.70\* | Suraj Unprotected v/s  RCH 2 BG IIUnprotected | | 2.46\* | RCH 2 BG II Unprotected v/s RCH 2 BG IIProtected | | 3.74\* |

A graph of a spider

AI-generated content may be incorrect.

**Fig 1: Occurrence of spiders in cotton fields of RCH 2 BG II and Suraj (protected   
 and unprotected) at MCRS, Surat during *Kharif* 2023-24 and 2024-25**



**Fig 2: Occurrence of spiders in cotton fields of RCH 2 BG II and Suraj   
 (unprotected) at MCRS, Surat during *Kharif* 2023-24 and 2024-25**

The seasonal incidence of spider populations was assessed in transgenic (RCH 2 BG II) and non-transgenic (Suraj) cotton under protected and unprotected conditions at MCRS, Surat, during the *Kharif* seasons of 2023–24 and 2024–25. The weekly monitoring revealed that the spider populations began to emerge from SMW 29, increasing gradually across all RCH 2 BG II and Suraj, protected and unprotected treatments, with peak densities observed between SMW 46 and 50, aligning with the reproductive and boll development phases of the crop. The Suraj unprotected treatment consistently recorded the highest mean spider population (0.72 spiders/plant), peaking at 1.20 spiders/plant in SMW 49. This reflects a highly conducive environment for predator buildup in non-*Bt*, insecticide-free plots. The RCH 2 BG II Unprotected also supported substantial predator populations, with a mean of 0.71 spiders/plant and a peak density of 1.24 spiders/plant in SMW 50. This indicates that Bt cotton, even in the absence of insecticide sprays, can still host an appreciable number of spiders. The protected plots of both cotton types consistently recorded lower spider populations throughout the season. RCH 2 BG II Protected had the lowest mean population (0.63 spiders/plant), likely due to the combined effects of *Bt* proteins and chemical applications, which may directly or indirectly suppress beneficial arthropods. The Suraj protected plots demonstrated an intermediate trend, with a mean spider population of 0.61 spiders/plant, suggesting that the non-*Bt* host plant still retains structural or ecological advantages for spider colonization despite protection. The paired t-tests performed to compare the treatment effects on spider abundance revealed that there exist a significant difference in spider population between Suraj unprotected and Suraj protected (-3.70\*), RCH 2 BG II Unprotected and RCH 2 BG II protected (2.46\*) and Suraj unprotected vs RCH 2 BG II unprotected (3.74\*) as presented in Table 2 and fig. 1 and 2. These results confirm that unprotected non-Bt cotton (Suraj) is most conducive to the buildup of spider populations, followed closely by unprotected *Bt* cotton. The protected cotton, regardless of crop type, demonstrated significantly reduced spider incidence, reinforcing the known suppressive effects of insecticide applications on non-target arthropods.

**Table 3: Incidence of spider in cotton fields of RCH 2 BG II and Suraj at RCRS, Bharuch during *Kharif* 2023-24 and 2024-25**

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **SMW** | | **Average number of spiders/plant** | | | | | | | | | | | | | | | | |
| **Transgenic (RCH 2 BG II)** | | | | | | | | **Non-transgenic (Suraj)** | | | | | | | | |
| **Protected** | | | | **Unprotected** | | | | **Protected** | | | | | **Unprotected** | | | |
| **2023** | **2024** | **Average** | | **2023** | | **2024** | **Average** | **2023** | | **2024** | | **Average** | **2023** | **2024** | | **Average** |
| 32 | | 0.20 | 0.32 | 0.26 | | 0.24 | | 0.36 | 0.30 | 0.16 | | 0.20 | | 0.18 | 0.20 | 0.28 | | 0.24 |
| 33 | | 0.24 | 0.28 | 0.26 | | 0.36 | | 0.40 | 0.38 | 0.20 | | 0.24 | | 0.22 | 0.32 | 0.36 | | 0.34 |
| 34 | | 0.36 | 0.36 | 0.36 | | 0.40 | | 0.44 | 0.42 | 0.24 | | 0.28 | | 0.26 | 0.36 | 0.40 | | 0.38 |
| 35 | | 0.40 | 0.40 | 0.40 | | 0.44 | | 0.48 | 0.46 | 0.28 | | 0.36 | | 0.32 | 0.40 | 0.48 | | 0.44 |
| 36 | | 0.44 | 0.44 | 0.44 | | 0.48 | | 0.56 | 0.52 | 0.32 | | 0.40 | | 0.36 | 0.44 | 0.52 | | 0.48 |
| 37 | | 0.48 | 0.48 | 0.48 | | 0.52 | | 0.60 | 0.56 | 0.32 | | 0.48 | | 0.40 | 0.48 | 0.56 | | 0.52 |
| 38 | | 0.52 | 0.52 | 0.52 | | 0.56 | | 0.64 | 0.60 | 0.36 | | 0.40 | | 0.38 | 0.52 | 0.60 | | 0.56 |
| 39 | | 0.56 | 0.48 | 0.52 | | 0.64 | | 0.68 | 0.66 | 0.40 | | 0.44 | | 0.42 | 0.56 | 0.64 | | 0.60 |
| 40 | | 0.60 | 0.56 | 0.58 | | 0.68 | | 0.72 | 0.70 | 0.40 | | 0.52 | | 0.46 | 0.60 | 0.68 | | 0.64 |
| 41 | | 0.66 | 0.60 | 0.63 | | 0.68 | | 0.76 | 0.72 | 0.44 | | 0.60 | | 0.52 | 0.68 | 0.72 | | 0.70 |
| 42 | | 0.68 | 0.64 | 0.66 | | 0.72 | | 0.76 | 0.74 | 0.48 | | 0.56 | | 0.52 | 0.72 | 0.76 | | 0.74 |
| 43 | | 0.72 | 0.68 | 0.70 | | 0.76 | | 0.80 | 0.78 | 0.64 | | 0.68 | | 0.66 | 0.76 | 0.82 | | 0.79 |
| 44 | | 0.76 | 0.72 | 0.74 | | 0.80 | | 0.84 | 0.82 | 0.76 | | 0.76 | | 0.76 | 0.84 | 0.88 | | 0.86 |
| 45 | | 0.80 | 0.72 | 0.76 | | 0.84 | | 0.88 | 0.86 | 0.80 | | 0.80 | | 0.80 | 0.88 | 0.92 | | 0.90 |
| 46 | | 0.80 | 0.80 | 0.80 | | 0.88 | | 0.92 | 0.90 | 0.84 | | 0.88 | | 0.86 | 0.92 | 0.96 | | 0.94 |
| 47 | | 0.84 | 0.92 | 0.88 | | 0.92 | | 0.96 | 0.94 | 0.88 | | 0.84 | | 0.86 | 0.92 | 1.00 | | 0.96 |
| 48 | | 0.68 | 0.84 | 0.76 | | 0.96 | | 1.04 | 1.00 | 0.92 | | 0.92 | | 0.92 | 0.96 | 0.96 | | 0.96 |
| 49 | | 0.88 | 0.96 | 0.92 | | 1.04 | | 1.12 | 1.08 | 0.96 | | 1.08 | | 1.02 | 1.04 | 0.88 | | 0.96 |
| 50 | | 0.92 | 1.08 | 1.00 | | 1.00 | | 1.16 | 1.08 | 1.04 | | 0.96 | | 1.00 | 0.92 | 0.84 | | 0.88 |
| 51 | | 0.88 | 1.04 | 0.96 | | 0.96 | | 1.20 | 1.08 | 0.88 | | 1.00 | | 0.94 | 0.88 | 0.80 | | 0.84 |
| 52 | | 0.84 | 1.00 | 0.92 | | 0.76 | | 1.24 | 1.00 | 0.84 | | 0.92 | | 0.88 | 0.68 | 0.72 | | 0.70 |
| **Mean** | | **0.63** | **0.66** | **0.65** | | **0.70** | | **0.79** | **0.74** | **0.58** | | **0.63** | | **0.61** | **0.67** | **0.70** | | **0.69** |
| **SD** | | **0.34** | **0.37** | **0.35** | | **0.33** | | **0.34** | **0.33** | **0.50** | | **0.43** | | **0.46** | **0.36** | **0.30** | | **0.33** |
|  | | | | | | | | | | | | | | | | | | |
| ‘t’ test | Suraj Unprotected v/s  Suraj -Protected | | | | 10.32\* | | Suraj Unprotected v/s RCH 2 BG II Unprotected | | | | 3.42\* | | RCH 2 BG II Unprotected v/s RCH 2 BG II Protected | | | | 2.82\* | |

A graph showing the growth of a number of people

AI-generated content may be incorrect.

**Fig 3: Occurrence of spiders in RCH 2 BG II and Suraj (protected and   
 unprotected) at MCRS, Surat during *Kharif* 2023-24 and 2024-25**

A graph with a line and a green line

AI-generated content may be incorrect.

**Fig 4.: Occurrence of spiders in cotton fields of RCH 2 BG II and Suraj   
 (unprotected) at MCRS, Surat during *Kharif* 2023-24 and 2024-25**

The SMW-wise comparative analysis of spider population per plant under RCH 2 BG II (Protected and Unprotected) and Suraj (Protected and Unprotected), during the *Kharif* season of 2023–2024, is presented in Figure 2. The data revealed distinct differences in predator buildup based on varietal and protection status. The spider populations increased progressively from SMW 29 across all treatments, reaching their peak between SMW 46 and 50, coinciding with the crop’s reproductive phase. The unprotected Suraj plots recorded the highest spider incidence, peaking at approximately 1.20 spiders/plant in 48th SMW, followed closely by RCH 2 BG II Unprotected, which peaked slightly earlier. The protected plots of both RCH 2 BG II and Suraj showed lower predator abundance, likely due to the application of insecticides reducing not only pest populations but also natural enemies like spiders. The RCH 2 BG II protected plots recorded the lowest spider population throughout the season, starting at ~0.20 spiders/plant in SMW 29 and peaking modestly toward the end of the season. The paired t-tests performed to compare the treatment effects on spider abundance revealed that there exists a significant difference in spider population between Suraj unprotected and Suraj protected (10.32\*), RCH 2 BG II Unprotected and RCH 2 BG II protected (2.82\*) and Suraj unprotected vs RCH 2 BG II unprotected (3.42\*) as presented in Table 3 and fig. 3 and 4. These results indicate that unprotected non-*Bt* (Suraj) cotton supports the highest spider diversity and density, followed by *Bt* unprotected fields, while protected plots suppress spider buildup due to chemical interventions.

* 1. **Population build-up of spiders in relation to abiotic and biotic factors**

To ascertain the influence of abiotic factors on the population fluctuation of spiders, the data on occurrence of spiders recorded in unprotected plots on RCH 2 BG II during *kharif* seasons of 2023-24 and 2024-25 at both the locations *viz*., Main Cotton Research Station, Surat and Regional Cotton Research Station, Bharuch and the weather parameters recorded at respective observatories were utilized for correlation studies considering larger acreage under *Bt* cotton in Gujarat and India. Similarly, the incidence data of spiders were also correlated with the biotic factors *viz*., density dependent variables especially soft bodied sucking pests and larvae of bollworms recorded in unprotected plot of the RCH 2 BG II at both the locations during kharif seasons of 2023-24 and 2024-25. The correlation studies of spiders were carried out with biotic and abiotic factors exclusively using two years’ data recorded in unprotected plots of RCH 2 BG II at Surat and Bharuch considering larger acreage under *Bt* cotton in Gujarat and India.

* + 1. **Main cotton research station, Surat**

As far as the influence of biotic factors on spider incidence is concerned, there was significant positive correlations between the spider populations and density dependent factors *viz*., aphid, jassid, whiteflies and mealybug populations in unprotected fixed plot of RCH 2 BG II during both the years, indicating that spider populations increased with the increased populations of sucking pests *viz*., aphid, jassid, whiteflies and mealybug. The correlations between spider population and thrips was found positive and significant during 2023-24 but it was not significant in 2024-25. Similarly, the correlation between spiders and pink bollworm infestation in flowers was found positive and significant during 2023-24 and not significant during 2024-25. Thus, the results revealed that spider populations affected by the sucking pest populations especially aphid, jassid, whiteflies, mealybug and also had less affinity with thrips and larvae of pink bollworms if there was shortage of prey insects or direct adverse effect of weather parameters on both the prey and spider population (Table 4, 5 & 6). As far as the influence of abiotic factors on spider is concerned, the correlations between the spider population and one-week preceding weather parameters revealed that there were significant positive correlations of spider populations with maximum temperature and sunshine hours and significant negative correlations with morning relative humidity, evening relative humidity, rain fall and rainy day during both the years (2023-24 & 2024-25). The correlation between spider population and minimum temperature was found to be negative but non-significant in 2023-24 and negative and significant in 2024-25 (Table 4, 7 & 8).

* + 1. **Regional cotton research station, Bharuch**

As far as the influence of biotic factors on spider incidence in unprotected fixed plot of RCH 2 BG II is concerned, there was significant positive correlations between the spider populations and density dependent factors *viz*., aphid, whiteflies and mealybug populations during both the years, indicating that spider populations increased with the increased populations of sucking pests *viz*., aphid, whiteflies and mealybug. The correlations between spider population and jassid, thrips and pink bollworm infestation in the flower were found to be non-significant during both years. Thus, the results revealed that spider populations affected by the sucking pest populations especially aphid, whiteflies, mealybug and also had less affinity with thrips, jassids and larvae of pink bollworms if there was shortage of prey insects or direct adverse effect of weather parameters on both the prey and spider population (Table 3, 5 & 6). As far as the influence of abiotic factors on spider is concerned, the correlations between the spider population and one-week preceding weather parameters revealed that there were significant positive correlations between spider populations and sunshine hours whereas significant negative correlations with minimum temperature, morning relative humidity, evening relative humidity and rainy day during both the years. The correlation between spider population and maximum temperature was found to be non-significant in both years. The correlations between spider populations and rainfall were found non-significant during 2023-24 and negative and significant during 2024-25 (Table 4, 7 & 8).

The present findings on correlations of spiders with biotic factors revealed that spider populations were strongly influenced by their prey populations, particularly soft-bodied insects such as aphids, whiteflies, and mealybugs, on RCH 2 BG II at both locations. Similar associations have been reported by Ali *et al*. (2020) and Patil *et al*. (2021), where spider abundance was positively correlated with prey availability in Bt and non-Bt cotton fields. Furthermore, jassids and small larvae within flowers also significantly influenced spider populations in the unprotected fixed plot of RCH 2 BG II at Surat. These observations suggest that spiders either prey directly on these pests or prefer habitats where such prey are abundant, as supported by Mujahid *et al*. (2020) and Bhat *et al*. (2013), who highlighted spiders’ role as opportunistic predators influenced by pest densities. Similar findings were reported by Ghate and Ranade (2002), emphasizing the role of spiders in regulating soft-bodied insect pests in cotton. The higher correlation with aphids and whiteflies suggests spiders play a significant role in suppressing these pests (Patel and Patel, 1972; Sankaran and Sebastian, 2005). Whiteflies may also attract web-building spiders due to their frequent aerial movement, increasing capture chances. In contrast, thrips showed weaker or inconsistent correlations, possibly due to their small size and lower susceptibility to spider predation, aligning with observations by Kranthi *et al*. (2005). The significant correlations with flower infestation of PBW indicate an indirect association, where higher pest-induced damage correlates with increased prey (larval) availability, thereby supporting spider abundance (Sharma and Pampapathy, 2006). Interestingly, very little infestation of *H. armigera* and *E. vitella* owing to the effect of *Bt* toxins, it was difficult to ascertain the role of spiders in suppressing lepidopteran pests, thereby limiting prey for spiders (Dhillon *et al*., 2011). This trend confirms that spiders in *Bt* fields may shift their prey spectrum toward sucking pests due to reduced bollworm incidence (Manjunath *et al*., 2016). Further, with respect to abiotic factors, the positive association between spider population and maximum temperature aligns with the findings by Ghate and Ranade (2002), who reported that higher temperatures favour spider activity through increased metabolic rates and enhanced prey availability. Similarly, the significant correlation with sunshine hours suggests that favorable light conditions promote web-building and foraging efficiency (Patel and Patel, 1972). Conversely, the negative correlation with humidity parameters can be attributed to the detrimental effects of high moisture on web integrity and prey movement. Sankaran and Sebastian (2005) noted that excessive humidity hampers web maintenance and reduces hunting success in web-building spiders. Furthermore, heavy rainfall and increased rainy days likely contribute to physical damage to webs, direct mortality and suppressed arthropod prey populations, leading to reduced spider abundance (Kumar and Rao, 2003). The strong inverse relationship with rainfall and rainy days emphasizes the vulnerability of spider populations to climatic disturbances. These findings corroborate the work of Sharma and Pampapathy (2006), who observed similar trends in predator populations under fluctuating weather conditions in cotton ecosystems. The absence of a significant correlation with minimum temperature suggests that cooler nighttime temperatures may not directly influence spider activity or survival. These results indicate that while *Bt* cotton fields offer reduced insecticide exposure, favorable abiotic conditions are crucial for sustaining spider populations. The integration of weather-based pest and predator forecasting in integrated pest management (IPM) strategies could enhance the conservation of natural enemies in *Bt* cotton (Dhillon *et al*., 2011; Manjunath *et al*., 2016). Further, the present findings on correlations of spiders with abiotic factors revealed that spider populations were strongly influenced by morning relative humidity, rainfall, and rainy days among the abiotic parameters on RCH 2 BG II at both locations. Additionally, maximum temperature and sunshine hours showed significant influence on spider populations in the unprotected fixed plot of RCH 2 BG II at Surat. This suggests that spiders are likely to associate with habitats favorable for their prey, which thrive under similar environmental conditions. These findings align with earlier observations by Patel and Patel (1972) and Ghate and Ranade (2002), who noted that high humidity levels support web-building activity, particularly among orb-weaving spiders like *Neoscona* and *Argiope*. The strong positive correlation with sunshine hours underscores the role of light availability in enhancing the activity of visually oriented hunters such as *Oxyopes spp.* and *Salticidae*, supporting the conclusions of Sankaran and Sebastian (2005) and Ali *et al*. (2020).

Rainfall and rainy days, which showed moderate to high positive correlations, likely promote favorable microclimates and boost the populations of prey such as aphids and whiteflies, thereby facilitating spider proliferation. This agrees with the findings of Bhat *et al*. (2013) and Farooq *et al*. (2023), who reported similar associations in cotton fields of Karnataka and Punjab, respectively. Additionally, the temperature range during the cropping season was an important factor, with moderate correlation for maximum temperature and slightly higher for minimum temperature. These patterns reflect the poikilothermic nature of spiders, whose metabolic and behavioural responses are regulated by ambient thermal conditions (Foelix, 2011).

**Table 4: Influence of biotic factors on the occurrence of spiders in RCH II BG II (2023-24 and 2024-25)**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Particulars** | **Correlation coefficient (r-values) of the spider population with** | | | |
| **Biotic (Density-dependent) factors** | | | |
| **MCRS Surat** | | **RCRS Bharuch** | |
| **2023** | **2024** | **2023** | **2024** |
| **Y1: Aphid/ 3 leaves** | 0.7180\*\* | 0.9315\*\* | 0.7473\*\* | 0.8967\*\* |
| **Y2: Jassid/3 leaves** | 0.8618\*\* | 0.4834\* | -0.1265 | 0.1246 |
| **Y3: Thrips/3 leaves** | 0.4734\* | -0.1071 | -0.1645 | -0.1445 |
| **Y4: Whitefly/3 leaves** | 0.9001\*\* | 0.8746\*\* | 0.8641\*\* | 0.6701\*\* |
| **Y5: Mealybug (no./5 cm apical shoot)** | 0.4910\*\* | 0.6852\*\* | 0.8559\*\* | 0.8704\*\* |
| **Y6: Infestation of pink bollworm (%)** | 0.7370\*\* | 0.1413 | 0.2429 | 0.0997 |

**Table 5: Influence of abiotic factors on the occurrence of spiders in RCH II BG II (2023-24 and 2024-25)**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Particulars** | **Correlation coefficient (r-values) of spider population with** | | | |
| **Abiotic (Density-independent) factors** | | | |
| **MCRS Surat** | | **RCRS Bharuch** | |
| **2023** | **2024** | **2023** | **2024** |
| **X1: Max. Temp. ℃** | 0.5072\*\* | 0.4987\*\* | -0.0068 | 0.0778 |
| **X2: Min Temp. ℃** | -0.2114 | -0.6242\*\* | -0.7306\*\* | -0.8626\*\* |
| **X3: Morning humidity (%)** | -0.7327\*\* | -0.8407\*\* | -0.6381\*\* | -0.5646\*\* |
| **X4: Evening humidity (%)** | -0.5930\*\* | -0.8480\*\* | -0.7475\*\* | -0.8311\*\* |
| **X5: Sunshine hour** | 0.6411\*\* | 0.8335\*\* | 0.3910 | 0.8045\*\* |
| **X6: Rainfall (mm)** | -0.6854\*\* | -0.6094\*\* | -0.0276 | -0.5863\*\* |
| **X7: Rainy day** | -0.8223\*\* | -0.7765\*\* | -0.4326\* | -0.6653\*\* |

\*Significant at 5 % level of significance \*\*Significant at 1% level of significance

A green and yellow squares with numbers

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**Fig. 5: Heatmap showing the influence of biotic factors on the incidence of   
 spiders in RCH II BG II (2023-24 and 2024-25)**

The dark green cells (*e.g*., Whitefly: 0.9001, Mealybug: 0.8704) indicate very strong positive correlations between these prey insects and spider populations — implying that as these pests increase, spider abundance also rises. The yellow to pale green cells (e.g., pink bollworm correlations ~0.10–0.24, Jassid at RCRS) reflect weak or non-significant correlations, suggesting inconsistent or indirect interactions. The pale yellow and orange cells (e.g., thrips at Bharuch) show low or slightly negative correlations, indicating minimal or inverse association (fig. 5).

A screenshot of a graph

AI-generated content may be incorrect.

**Fig. 6: Heatmap showing the influence of abiotic factors on the   
 occurrence of spiders in RCH II BG II (2023-24 and 2024-25)**

The dark and medium green cells, *e.g. s*unshine hour showed strong positive correlations at MCRS Surat (2023, 2024) and RCRS Bharuch 2024 (*e.g*., 0.6411, 0.8335 and 0.8045 respectively), indicating that longer sunshine duration enhances spider activity. The dark orange to red cells *e.g.* rainy days, morning and evening Humidity and minimum temperature consistently showed strong negative correlations (*e.g*., −0.8407, −0.8480, −0.8626) — suggesting these conditions negatively affect spider abundance, likely due to reduced foraging or survival rates. The yellow cells, *e.g.* maximumt temperature at RCRS Bharuch (2023 and 2024) showed very weak or non-significant correlations (*e.g*., −0.0068, 0.0778), indicating minimal direct influence (fig. 6).

1. **CONCLUSIONS AND RECOMMENDATIONS**

The results revealed that biotic factors, specifically the population densities of aphids, whiteflies, and mealybugs, showed strong and consistent positive correlations with spider abundance at both locations and across both years. Jassid and pink bollworm also showed significant positive associations at MCRS but not at RCRS. In contrast, thrips had weak or non-significant correlations with spider presence. The abiotic factors, maximum temperature and sunshine hours, exhibited significant positive correlations with spider populations at MCRS, indicating that warmer and sunnier conditions favour spider activity. Conversely, morning and evening humidity, rainfall, and a number of rainy days had significant negative correlations, suggesting that excessive moisture adversely impacts spider web integrity, foraging behavior, and prey availability. At RCRS, the minimum temperature also showed a strong negative correlation with spider abundance. The strong correlation of spider abundance with soft-bodied sucking pests like aphids, whiteflies, and mealybugs underscores the critical role of spiders as natural regulators of pest populations. The sensitivity of spider populations to temperature, humidity, and rainfall conditions emphasizes the need to consider climatic variables while designing spider-conservation-friendly agricultural practices.

**Table 6: Occurrence of spider and insect pests in unprotected plot of RCH 2 BG II and weather parameters at MCRS, Surat (2023)**

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **SMW** | **Spider** | **Aphid**  **(Y1)** | **Jasid**  **(Y2)** | **Thrips**  **(Y3)** | **Whitefly**  **(Y4)** | **Mealybug**  **(Y5)** | **PBW Rosette flower (%) (Y6)** | **Temperature (0C)** | | **Humidity (%)** | | **Sunshine hour**  **(X5)** | **Rainfall**  **(mm)**  **(X6)** | **Rainy days**  **(X7)** |
| **Max.**  **(X1)** | **Min.**  **(X2)** | **Morn. (X3)** | **Even. (X4)** |
| 29 | 0.16 | 0.60 | 0.00 | 2.00 | 1.00 | 0.00 | 0.00 | 32.0 | 26.9 | 100 | 80 | 2.90 | 84.50 | 6 |
| 30 | 0.20 | 0.80 | 0.20 | 2.40 | 0.80 | 0.00 | 0.00 | 30.7 | 26.3 | 100 | 86 | 0.70 | 128.50 | 7 |
| 31 | 0.24 | 2.20 | 0.40 | 6.20 | 0.70 | 0.00 | 0.00 | 30.2 | 26.7 | 100 | 90 | 1.40 | 103.50 | 6 |
| 32 | 0.28 | 3.20 | 0.90 | 7.40 | 0.90 | 0.00 | 0.00 | 3.70 | 26.2 | 100 | 91 | 1.20 | 145.00 | 7 |
| 33 | 0.36 | 4.30 | 1.20 | 14.2 | 1.40 | 0.00 | 0.00 | 30.2 | 26.8 | 100 | 93 | 1.30 | 13.00 | 6 |
| 34 | 0.48 | 3.20 | 2.00 | 16.2 | 2.20 | 0.00 | 0.00 | 30.8 | 26.3 | 100 | 90 | 2.10 | 19.50 | 5 |
| 35 | 0.56 | 4.50 | 3.20 | 22.2 | 2.60 | 0.00 | 0.00 | 31.3 | 27.0 | 100 | 86 | 2.60 | 0.50 | 0 |
| 36 | 0.64 | 5.80 | 3.60 | 28.4 | 2.80 | 0.00 | 0.00 | 31.4 | 26.7 | 100 | 87 | 3.30 | 24.00 | 3 |
| 37 | 0.68 | 6.20 | 5.20 | 32.4 | 2.80 | 0.10 | 0.00 | 32.8 | 27.1 | 99 | 75 | 7.80 | 0.50 | 0 |
| 38 | 0.72 | 8.80 | 5.40 | 35.0 | 2.90 | 0.20 | 1.30 | 31.6 | 27.6 | 95 | 81 | 6.70 | 51.50 | 3 |
| 39 | 0.76 | 11.8 | 6.00 | 37.6 | 3.20 | 0.30 | 1.40 | 31.6 | 27.5 | 87 | 74 | 5.20 | 34.00 | 2 |
| 40 | 0.80 | 14.6 | 7.20 | 32.4 | 3.70 | 0.40 | 2.65 | 31.8 | 26.7 | 81 | 76 | 3.90 | 8.80 | 3 |
| 41 | 0.84 | 19.6 | 8.40 | 35.4 | 3.80 | 0.20 | 3.00 | 31.7 | 26.4 | 81 | 67 | 5.30 | 3.00 | 0 |
| 42 | 0.88 | 25.4 | 9.40 | 31.4 | 4.60 | 0.30 | 5.50 | 34.3 | 27.3 | 77 | 62 | 4.30 | 0.00 | 0 |
| 43 | 0.92 | 30.1 | 10.8 | 28.6 | 5.80 | 0.60 | 8.40 | 36.4 | 28.4 | 86 | 78 | 4.90 | 0.00 | 0 |
| 44 | 0.96 | 35.2 | 13.4 | 30.2 | 6.40 | 0.60 | 9.30 | 36.1 | 27.7 | 66 | 56 | 5.00 | 0.00 | 0 |
| 45 | 1.00 | 38.6 | 12.6 | 26.8 | 7.60 | 0.80 | 8.10 | 34.6 | 24.1 | 66 | 56 | 4.80 | 0.00 | 0 |
| 46 | 1.08 | 37.0 | 9.6 | 23.2 | 6.00 | 1.00 | 7.20 | 36.6 | 21.9 | 60 | 40 | 5.40 | 0.00 | 0 |
| 47 | 1.00 | 35.6 | 6.8 | 14.4 | 6.20 | 1.20 | 4.20 | 38.4 | 23.0 | 60 | 29 | 6.20 | 0.00 | 0 |
| 48 | 0.92 | 41.4 | 6.40 | 6.80 | 5.40 | 1.30 | 3.10 | 34.9 | 22.3 | 61 | 33 | 4.70 | 0.00 | 0 |
| 49 | 0.84 | 43.6 | 5.80 | 2.40 | 4.00 | 1.40 | 2.10 | 33.4 | 21.6 | 85 | 51 | 3.00 | 0.00 | 0 |
| 50 | 0.80 | 38.2 | 3.40 | 0.00 | 3.70 | 1.20 | 0.00 | 22.1 | 14.1 | 65 | 28 | 0.40 | 88.00 | 1 |
| 51 | 0.72 | 46.8 | 2.40 | 0.00 | 2.60 | 1.60 | 0.00 | 30.5 | 20.6 | 77 | 44 | 4.40 | 0.00 | 0 |
| 52 | 0.60 | 41.4 | 1.00 | 0.00 | 1.00 | 1.70 | 0.00 | 31.4 | 19.2 | 95 | 38 | 3.80 | 0.00 | 0 |
| 1 | 0.48 | 30.2 | 0.00 | 0.00 | 0.00 | 1.40 | 0.00 | 29.2 | 20.7 | 62 | 35 | 3.90 | 0.00 | 0 |
| **Av.** | **0.68** | **21.16** | **5.01** | **17.42** | **3.28** | **0.57** | **2.25** | **32.2** | **24.5** | **84.73** | **62.68** | **3.82** | **27.09** | **1.88** |

**Table 7: Occurrence of spider and insect pests in unprotected plot of RCH 2 BG II and weather parameters at MCRS, Surat (2024)**

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **SMW** | **Spider** | **Aphid**  **(Y1)** | **Jasid**  **(Y2)** | **Thrips**  **(Y3)** | **Whitefly**  **(Y4)** | **Mealybug**  **(Y5)** | **PBW Rosette flower (%) (Y6)** | **Temperature** | | **Humidity** | | **Sunshine hour**  **(X5)** | **Rainfall**  **(mm)**  **(X6)** | **Rainy days**  **(X7)** |
| **Max.**  **(X1)** | **Min.**  **(X2)** | **Morn. (X3)** | **Even. (X4)** |
| 30 | 0.24 | 0.00 | 0.20 | 2.40 | 0.20 | 0.00 | 0.00 | 29.1 | 25.4 | 86.0 | 81.0 | 2.20 | 60.0 | 4 |
| 31 | 0.28 | 0.50 | 0.30 | 6.20 | 0.20 | 0.00 | 0.00 | 30.0 | 25.3 | 84.0 | 80.0 | 1.20 | 123.0 | 4 |
| 32 | 0.32 | 1.20 | 0.80 | 7.40 | 0.40 | 0.00 | 0.00 | 29.3 | 24.7 | 90.0 | 85.0 | 1.30 | 272.0 | 5 |
| 33 | 0.40 | 2.60 | 1.20 | 14.30 | 0.60 | 0.00 | 0.00 | 30.9 | 26.7 | 80.0 | 75.0 | 1.60 | 28.0 | 3 |
| 34 | 0.44 | 3.20 | 2.20 | 16.20 | 1.10 | 0.00 | 0.00 | 29.9 | 27.3 | 75.0 | 68.0 | 1.20 | 18.0 | 4 |
| 35 | 0.48 | 4.10 | 3.40 | 22.40 | 1.80 | 0.00 | 0.00 | 29.3 | 26.7 | 78.0 | 69.0 | 3.10 | 20.0 | 2 |
| 36 | 0.52 | 5.10 | 3.50 | 28.40 | 2.00 | 0.00 | 0.10 | 27.6 | 25.4 | 88.0 | 83.0 | 1.60 | 126.0 | 3 |
| 37 | 0.60 | 5.60 | 5.30 | 32.40 | 2.20 | 0.00 | 0.42 | 29.9 | 27.3 | 87.0 | 82.0 | 2.40 | 59.0 | 3 |
| 38 | 0.64 | 8.00 | 5.40 | 35.20 | 2.60 | 0.00 | 1.00 | 28.4 | 25.7 | 81.0 | 78.0 | 3.90 | 76.0 | 6 |
| 39 | 0.68 | 13.40 | 6.00 | 37.30 | 3.00 | 0.20 | 1.45 | 28.4 | 25.6 | 80.0 | 75.0 | 5.90 | 57.0 | 2 |
| 40 | 0.72 | 17.60 | 7.20 | 32.40 | 3.60 | 0.20 | 1.78 | 29.9 | 26.0 | 75.0 | 70.0 | 7.10 | 0.00 | 0 |
| 41 | 0.76 | 22.00 | 8.80 | 35.50 | 3.40 | 0.00 | 3.10 | 27.1 | 26.0 | 88.0 | 81.0 | 2.40 | 119.0 | 4 |
| 42 | 0.80 | 27.20 | 9.40 | 31.20 | 4.20 | 0.20 | 4.25 | 32.5 | 25.6 | 69.0 | 62.0 | 8.30 | 0.00 | 0 |
| 43 | 0.88 | 29.00 | 10.80 | 28.20 | 4.40 | 0.40 | 5.60 | 33.4 | 23.8 | 67.0 | 61.0 | 5.80 | 39.0 | 2 |
| 44 | 0.88 | 33.80 | 13.20 | 30.60 | 5.10 | 0.40 | 3.70 | 35.3 | 25.1 | 62.0 | 56.0 | 5.70 | 17.0 | 1 |
| 45 | 0.92 | 41.80 | 12.40 | 26.60 | 5.60 | 0.60 | 0.00 | 35.4 | 23.6 | 55.0 | 47.0 | 7.60 | 0.00 | 0 |
| 46 | 0.96 | 45.60 | 9.80 | 23.40 | 5.70 | 0.80 | 0.00 | 37.6 | 22.7 | 49.0 | 43.0 | 8.10 | 0.00 | 0 |
| 47 | 1.00 | 51.60 | 6.80 | 14.40 | 5.80 | 1.00 | 0.00 | 35.0 | 21.6 | 55.0 | 45.0 | 7.10 | 0.00 | 0 |
| 48 | 1.08 | 53.40 | 6.40 | 6.80 | 6.20 | 1.00 | 0.00 | 33.3 | 21.6 | 57.0 | 48.0 | 8.00 | 0.00 | 0 |
| 49 | 1.12 | 55.60 | 5.00 | 2.40 | 5.40 | 1.20 | 0.00 | 31.1 | 19.9 | 55.5 | 45.0 | 8.60 | 0.00 | 0 |
| 50 | 1.20 | 54.20 | 3.10 | 0.00 | 4.60 | 1.40 | 0.00 | 30.9 | 19.6 | 55.0 | 45.0 | 7.60 | 0.00 | 0 |
| 51 | 1.00 | 57.60 | 2.20 | 0.00 | 3.60 | 1.60 | 0.00 | 30.0 | 16.7 | 58.0 | 49.0 | 5.10 | 0.00 | 0 |
| 52 | 0.96 | 49.80 | 1.00 | 0.00 | 2.00 | 1.80 | 0.00 | 29.6 | 15.6 | 58.0 | 49.0 | 3.90 | 0.00 | 0 |
| 1 | 0.72 | 45.00 | 0.00 | 0.00 | 1.20 | 2.20 | 0.00 | 28.6 | 16.3 | 58.0 | 49.0 | 3.70 | 0.00 | 0 |
| **Av.** | **0.73** | **26.16** | **5.18** | **18.07** | **3.12** | **0.50** | **0.89** | **30.9** | **23.5** | **70.4** | **63.6** | **4.73** | **42.25** | **1.79** |

**Table 8: Occurrence of spider and insect pests in unprotected plot of RCH 2 BG II and weather parameters at RCRS, Bharuch (2023)**

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **S**  **M**  **W** | **Spider** | **Aphid**  **(Y1)** | **Jasid**  **(Y2)** | **Thrips**  **(Y3)** | **Whitefly**  **(Y4)** | **Mealybug**  **(Y5)** | **PBW Rosette flower (%)**  **(Y6)** | **Temperature (0C)** | | **Humidity (%)** | | **Sunshine hour**  **(X5)** | **Rainfall**  **(mm)**  **(X6)** | **Rainy days**  **(X7)** |
| **Max.**  **(X1)** | **Min.**  **(X2)** | **Morn. (X3)** | **Even. (X4)** |
| 32 | 0.24 | 0.20 | 1.00 | 0.80 | 0.00 | 0.00 | 0.00 | 31.6 | 26.5 | 82.6 | 66.4 | 3.00 | 0.90 | 0.30 |
| 33 | 0.36 | 0.30 | 1.20 | 1.20 | 0.00 | 0.00 | 0.00 | 31.8 | 26.9 | 80.1 | 63.9 | 1.80 | 0.90 | 0.30 |
| 34 | 0.40 | 0.30 | 1.40 | 5.60 | 0.00 | 0.00 | 0.00 | 32.2 | 26.5 | 81.3 | 64.1 | 2.40 | 0.00 | 0.00 |
| 35 | 0.44 | 0.40 | 2.00 | 10.40 | 0.20 | 0.00 | 0.00 | 31.4 | 26.5 | 76.9 | 62.3 | 2.50 | 1.10 | 0.10 |
| 36 | 0.48 | 0.60 | 3.20 | 23.60 | 0.30 | 0.00 | 0.00 | 34.1 | 26.9 | 79.3 | 54.6 | 6.90 | 0.00 | 0.00 |
| 37 | 0.52 | 0.80 | 4.60 | 24.20 | 0.60 | 0.00 | 0.00 | 34.9 | 26.4 | 77.3 | 55.0 | 7.80 | 7.60 | 0.30 |
| 38 | 0.56 | 0.90 | 5.40 | 22.40 | 0.70 | 0.10 | 0.00 | 31.1 | 25.5 | 75.6 | 62.9 | 5.10 | 1.10 | 0.30 |
| 39 | 0.64 | 1.20 | 6.60 | 20.40 | 1.00 | 0.20 | 1.75 | 29.8 | 25.7 | 82.1 | 66.3 | 1.60 | 6.90 | 0.60 |
| 40 | 0.68 | 1.60 | 7.00 | 21.20 | 1.20 | 0.10 | 2.15 | 31.5 | 24.9 | 71.7 | 56.4 | 3.70 | 14.00 | 0.30 |
| 41 | 0.68 | 1.80 | 5.20 | 19.60 | 1.30 | 0.20 | 2.60 | 34.7 | 25.9 | 58.1 | 34.0 | 8.50 | 0.00 | 0.00 |
| 42 | 0.72 | 3.60 | 4.60 | 23.40 | 0.90 | 0.40 | 3.80 | 36.5 | 25.5 | 43.7 | 33.7 | 9.10 | 0.00 | 0.00 |
| 43 | 0.76 | 5.60 | 3.60 | 18.80 | 1.40 | 0.50 | 4.10 | 36.2 | 25.2 | 38.6 | 23.9 | 9.00 | 0.00 | 0.00 |
| 44 | 0.80 | 6.20 | 3.40 | 16.40 | 2.40 | 0.60 | 3.90 | 36.1 | 25.8 | 36.0 | 28.3 | 9.40 | 0.00 | 0.00 |
| 45 | 0.84 | 18.20 | 2.80 | 5.60 | 2.50 | 0.90 | 3.45 | 35.8 | 24.7 | 41.0 | 25.3 | 9.20 | 0.00 | 0.00 |
| 46 | 0.88 | 9.00 | 2.20 | 6.80 | 2.70 | 1.10 | 2.45 | 36.1 | 24.9 | 37.6 | 18.3 | 9.20 | 0.00 | 0.00 |
| 47 | 0.92 | 9.60 | 2.00 | 5.60 | 2.40 | 1.20 | 1.10 | 35.6 | 21.9 | 36.3 | 25.1 | 9.10 | 0.00 | 0.00 |
| 48 | 0.96 | 11.20 | 1.60 | 4.80 | 1.80 | 1.40 | 0.00 | 34.1 | 19.6 | 44.4 | 28.3 | 8.50 | 0.00 | 0.00 |
| 49 | 1.04 | 13.60 | 1.40 | 6.40 | 2.00 | 1.60 | 0.00 | 29.4 | 17.8 | 66.7 | 45.4 | 0.90 | 6.70 | 0.10 |
| 50 | 1.00 | 17.00 | 1.20 | 5.00 | 1.60 | 1.90 | 0.00 | 28.9 | 19.1 | 75.4 | 42.7 | 3.40 | 1.20 | 0.10 |
| 51 | 0.96 | 20.00 | 1.00 | 4.40 | 1.40 | 1.80 | 0.00 | 28.7 | 18.1 | 58.7 | 35.0 | 7.50 | 0.00 | 0.00 |
| 52 | 0.76 | 24.20 | 1.00 | 3.00 | 1.60 | 1.90 | 0.00 | 25.3 | 16.1 | 43.7 | 26.4 | 6.60 | 0.00 | 0.00 |
| **Av.** | **0.70** | **6.97** | **2.97** | **11.89** | **1.24** | **0.66** | **1.20** | **32.7** | **23.8** | **61.3** | **43.7** | **5.96** | **1.92** | **0.11** |

**Table 9: Occurrence of spider and insect pests in unprotected plot of RCH 2 BG II and weather parameters at RCRS, Bharuch (2024)**

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **SMW** | **Spider** | **Aphid**  **(Y1)** | **Jasid**  **(Y2)** | **Thrips**  **(Y3)** | **Whitefly**  **(Y4)** | **Mealybug**  **(Y5)** | **PBW Rosette flower (%) (Y6)** | **Temperature (0C)** | | **Humidity (%)** | | **Sunshine hour**  **(X5)** | **Rainfall**  **(mm)**  **(X6)** | **Rainy days**  **(X7)** |
| **Max.**  **(X1)** | **Min.**  **(X2)** | **Morn. (X3)** | **Even. (X4)** |
| **32** | 0.36 | 0.00 | 0.70 | 0.40 | 0.00 | 0.00 | 0.00 | 29.8 | 25.7 | 81.0 | 68.6 | 0.50 | 45.20 | 4 |
| **33** | 0.40 | 0.20 | 1.20 | 1.00 | 0.00 | 0.00 | 0.00 | 31.0 | 25.7 | 90.4 | 82.9 | 1.70 | 45.60 | 1 |
| **34** | 0.44 | 0.20 | 1.40 | 1.60 | 0.00 | 0.00 | 0.00 | 31.7 | 25.4 | 81.0 | 77.0 | 0.00 | 52.00 | 3 |
| **35** | 0.48 | 0.30 | 1.70 | 2.20 | 0.00 | 0.00 | 0.00 | 32.3 | 26.2 | 78.4 | 73.0 | 4.00 | 180.0 | 2 |
| **36** | 0.56 | 0.30 | 2.60 | 5.80 | 0.20 | 0.00 | 0.00 | 29.6 | 24.1 | 79.7 | 59.1 | 6.20 | 77.50 | 2 |
| **37** | 0.60 | 0.40 | 3.10 | 13.60 | 0.60 | 0.00 | 0.00 | 29.2 | 24.2 | 83.0 | 62.7 | 5.80 | 189.0 | 5 |
| **38** | 0.64 | 0.40 | 3.40 | 14.80 | 0.80 | 0.00 | 0.00 | 30.5 | 24.7 | 87.1 | 72.0 | 2.30 | 46.00 | 1 |
| **39** | 0.68 | 0.50 | 3.60 | 16.40 | 0.90 | 0.00 | 1.68 | 33.0 | 26.6 | 79.7 | 61.6 | 4.70 | 0.00 | 0 |
| **40** | 0.72 | 0.60 | 4.60 | 17.20 | 1.00 | 0.80 | 2.23 | 34.3 | 26.8 | 80.1 | 60.0 | 5.50 | 102.5 | 4 |
| **41** | 0.76 | 0.70 | 5.80 | 20.20 | 1.20 | 0.60 | 2.35 | 32.5 | 24.9 | 74.1 | 52.6 | 6.30 | 0.00 | 0 |
| **42** | 0.76 | 1.30 | 8.70 | 16.00 | 1.30 | 0.80 | 2.62 | 34.8 | 25.3 | 83.0 | 68.9 | 4.00 | 34.20 | 2 |
| **43** | 0.80 | 1.80 | 9.00 | 11.20 | 1.40 | 1.20 | 3.15 | 34.3 | 25.9 | 70.7 | 69.0 | 8.20 | 52.20 | 2 |
| **44** | 0.84 | 2.20 | 10.20 | 10.40 | 1.60 | 0.80 | 3.40 | 34.4 | 24.5 | 52.9 | 42.1 | 8.50 | 0.00 | 0 |
| **45** | 0.88 | 9.30 | 6.60 | 7.60 | 1.70 | 1.20 | 4.75 | 34.9 | 22.9 | 51.6 | 36.4 | 6.50 | 0.00 | 0 |
| **46** | 0.92 | 10.50 | 5.80 | 4.40 | 1.90 | 1.40 | 3.25 | 32.1 | 23.1 | 81.7 | 53.4 | 6.00 | 0.00 | 0 |
| **47** | 0.96 | 17.60 | 4.20 | 4.30 | 2.20 | 1.60 | 1.30 | 33.3 | 21.5 | 73.6 | 40.1 | 7.60 | 0.00 | 0 |
| **48** | 1.04 | 19.40 | 3.00 | 3.80 | 1.80 | 1.80 | 0.00 | 33.4 | 19.6 | 74.9 | 39.9 | 7.50 | 0.00 | 0 |
| **49** | 1.12 | 22.20 | 2.40 | 2.60 | 1.40 | 1.60 | 0.00 | 33.1 | 20.0 | 76.0 | 45.4 | 7.30 | 0.00 | 0 |
| **50** | 1.16 | 26.00 | 2.10 | 2.40 | 1.20 | 1.40 | 0.00 | 32.5 | 18.6 | 53.1 | 39.0 | 8.80 | 0.00 | 0 |
| **51** | 1.20 | 24.30 | 1.80 | 2.00 | 0.80 | 1.20 | 0.00 | 28.7 | 17.9 | 46.1 | 29.0 | 8.80 | 0.00 | 0 |
| **52** | 1.24 | 30.10 | 1.40 | 1.60 | 0.80 | 1.20 | 0.00 | 28.4 | 17.2 | 79.7 | 50.0 | 6.70 | 0.00 | 0 |
| **Av.** | **0.79** | **8.01** | **3.97** | **7.60** | **0.99** | **0.60** | **1.18** | **32.1** | **23.4** | **74.2** | **56.3** | **5.57** | **39.25** | **1.24** |

**APPENDIX**

|  |  |  |
| --- | --- | --- |
| **APPENDIX-1: Insecticide applied in protected blocks of cotton at Surat and Bharuch (2023-25)** | | |
| **Insect-pest** | ***Bt* cotton hybrid**  **(RCH 2 BG II)** | **Non-*Bt* cotton variety (Suraj)** |
| Sucking pests and bollworms | **(For Sucking pests)**  Flonicamid 50 WG  Thiamethoxam 25 WG  Buprofezin 25 SC  Dimethoate 30 EC | |
| (**Only for pink bollworm**)  Emamectin benzoate 5 SG | (**For all bollworms**)  Chlorpyriphos 20 EC  Quinalphos 25 EC  Indoxacarb 14.5 SC |

**COMPETING INTERESTS DISCLAIMER:**

Authors have declared that they have no known competing financial interests OR non-financial interests OR personal relationships that could have appeared to influence the work reported in this paper.

**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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