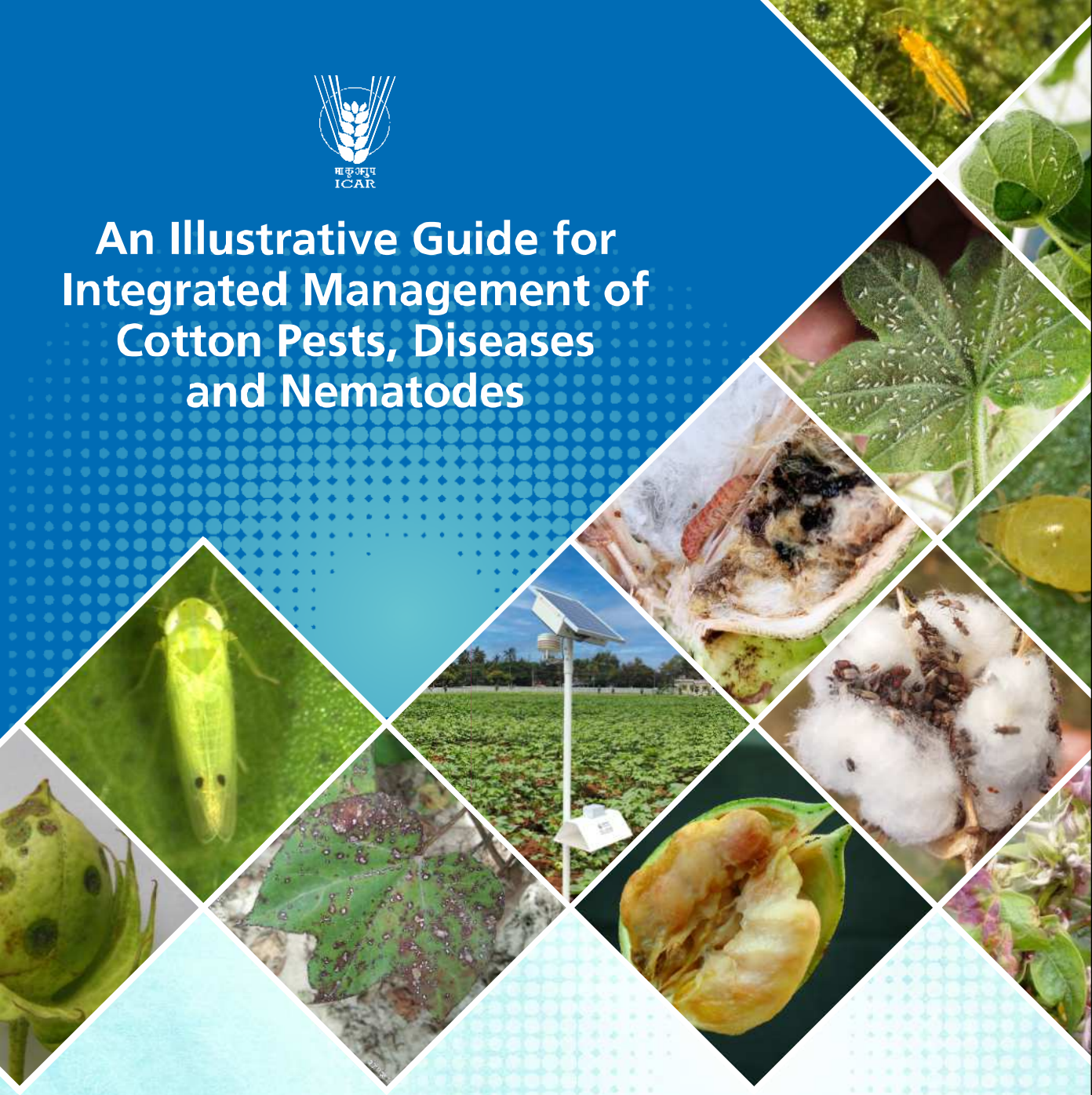
An Illustrative Guide for Integrated Management of Cotton Pests, Diseases and Nematodes

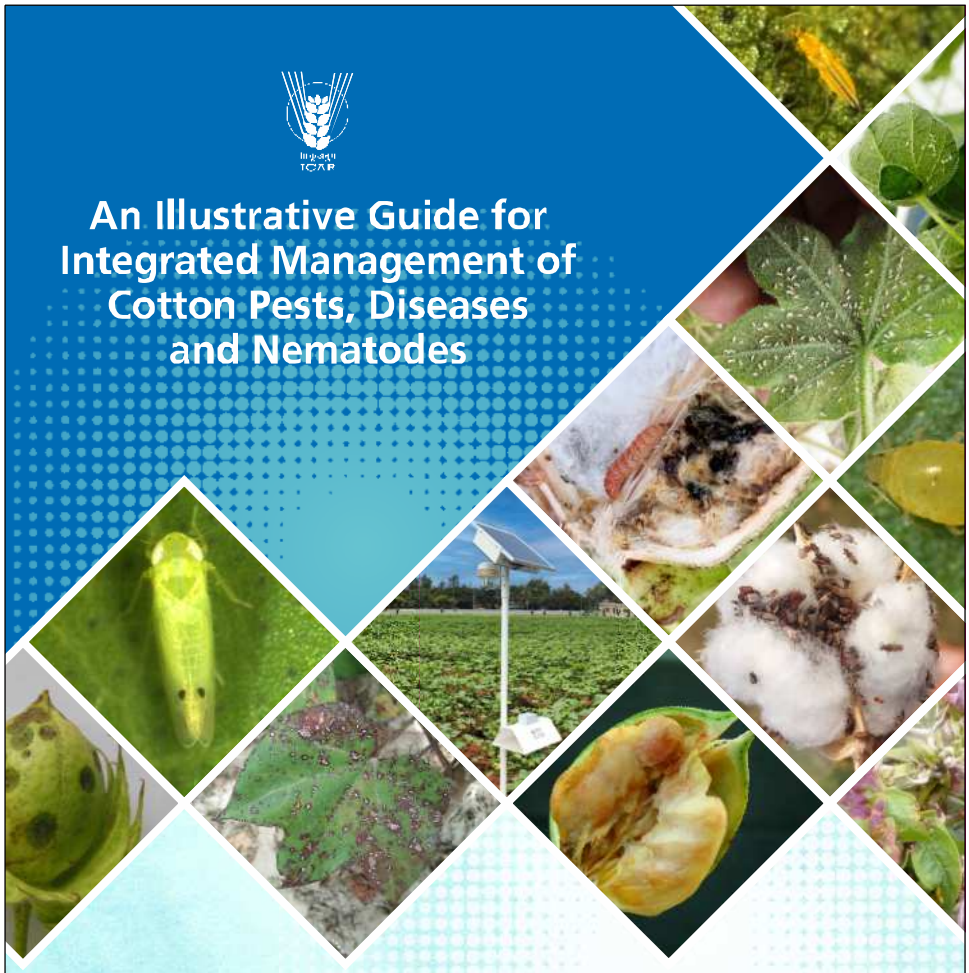


V.S. Nagrare, Rishi Kumar, Shivaji Thube, S.K. Sain, Vivek Shah,
Babasaheb B. Fand, Rachna Pande, S.P. Gawande, D.T. Nagrale,
N.S. Hiremani, Priyank H. Mhatre, K. Rameash, K. Shankarganesh, M. Amutha,
A. Sampathkumar, P. Valarmathi, J. Gulsar Banu, G.T. Behere, V.N. Waghmare

ICAR-CENTRAL INSTITUTE FOR COTTON RESEARCH

Post Bag No 2, Shankar Nagar P. O., Nagpur - 440010 (M.S.), India

An Illustrative Guide for Integrated Management of Cotton Pests, Diseases and Nematodes



V.S. Nagrare, Rishi Kumar, Shivaji Thube, S.K. Sain, Vivek Shah, Babasaheb B. Fand, Rachna Pande, S.P. Gawande, D.T. Nagrale, N.S. Hiremani, Priyank H. Mhatre, K. Rameash, K. Shankarganesh, M. Amutha, A. Sampathkumar, P. Valarmathi, J. Gulsar Banu, G.T. Behere, V.N. Waghmare

ICAR-CENTRAL INSTITUTE FOR COTTON RESEARCH

Post Bag No. 2, Shankar Nagar P.O., NAGPUR - 440010 (M.S.), India

ISO 9001: 2015

An Illustrative Guide for Integrated Management of Cotton Pests, Diseases and Nematodes

Authors : V.S. Nagrare, Rishi Kumar, Shivaji Thube, S.K. Sain, Vivek Shah, Babasaheb B. Fand, Rachna Pande, S.P. Gawande, D.T. Nagrale, N.S. Hiremani, Priyank H. Mhatre, K. Rameash, K. Shankarganesh, M. Amutha, A. Sampathkumar, P. Valarmathi, J. Gulsar Banu, G.T. Behere, V.N. Waghmare

Citation : Nagrare V.S., Kumar Rishi, Thube Shivaji, Sain S.K., Shah Vivek, Fand Babasaheb B., Pande Rachna, Gawande S.P., Nagrale D.T., Hiremani N.S., Mhatre P.H., Rameash K., Shankarganesh K., Amutha M., Sampathkumar A., Valarmathi P., Gulsar Banu J., Behere G.T., Waghmare V.N. (2026) An Illustrative Guide for Integrated Management of Cotton Pests, Diseases and Nematodes. ICAR- Central Institute for Cotton Research, Nagpur. PP - 126

Published by : **Dr. V.N. Waghmare**
Director
ICAR - Central Institute for Cotton Research
Post Bag No.2, Shankar Nagar P.O., Nagpur 440010
Website: www.cicr.org.in
E-mail: cicrnagpur@gmail.com

Printed : July, 2026

Printed at : M/s. Nag Mudranalay, Nagpur

Price : **Rs. 250/-**

© All rights are reserved with ICAR-CICR.

FOREWORD

Dr. V. N. Waghmare
Director
ICAR-Central Institute for Cotton Research
Nagpur (Maharashtra)

Cotton is a vital cash crop ofIndia with largest cultivation acreage globally. However, wide gaps in productivity persist due to various biotic and abiotic stresses, challenges that often become unmanageable due to delayed or incorrect diagnosis. In the post-*Bt* era, the widespread adoption of hybrids has shifted crop management practices towards more input-intensive system. Further, genetic uniformity across vast areas has favoured built-up of pest population. Consequently, growers face unprecedented challenges as several historically minor insect pests, pathogens, and nematodes have now emerged as major threats to cotton cultivation.

Among current biotic stresses, insect pests such as cotton whitefly, jassids, thrips, and pink bollworm pose significant threats across all the three cotton-growing zones of India, while the tea mosquito bug, mirids and stem weevils cause localized damage in South India. The dusky cotton bug is becoming a serious threat in North India. Among diseases, Cotton Leaf Curl Disease (CLCuD), grey mildew, bacterial blight, fungal and bacterial boll rots, leaf spots, root rot, and tobacco streak virus have become increasingly severe in recent years, heavily influenced by host genotypes and shifting climatic conditions. Additionally, plantparasitic nematodes inhabiting the cotton rhizosphere, particularly root-knot nematode and reniform nematode, have been documented as critical constraints to crop health.

To address these challenges, this book provides a comprehensive guide for each major insect pest, disease, and nematode affecting cotton. It covers key aspects of national importance, including economic impact, nature of damage, seasonal incidence, Bt-resistance status, stage-wise identification characteristics, life cycles, surveillance protocols, and integrated management strategies.

By offering a compact, yet exhaustive reference, this publication aims to help growers, scientists, students and extension workers to accurately diagnose biotic stresses directly in the field- a critical prerequisite for effective management. We trust this publication will serve as a valuable resource for all stakeholders in Indian cotton production.

V.N. Waghmare

CONTENTS

An Illustrative Guide for Integrated Management of Cotton Pests, Diseases and Nematodes

INTRODUCTION

Global cotton area, production and productivity: India's perspective

Cotton remains the leading natural fiber for global textile and garment production, cultivated across more than 70 countries. China, India, Brazil, the United States, and Pakistan lead global cotton production. India holds the largest share of land, accounting for 11.36 million ha of the world's 29.84 million ha. Despite this vast acreage, India's productivity remains a challenge; at 448 kg of lint per ha, it trails significantly behind the global average of 834 lint kg per ha (ICAC 2025).

Cotton species grown in India

India is unique country that cultivate all four cultivated cotton species: upland cotton (*Gossypium hirsutum* L.), Asian cotton / *Desi* cotton (*G. arboreum* L.), Levant cotton (*G. herbaceum* L.), and Sea Island cotton (*G. barbadense* L.). While *G. hirsutum* dominates global fiber production at over 90%, followed by *G. barbadense* (3–4%) and the remaining two species (2% each). In the Indian context, *G. hirsutum*, genetically modified Bt-cotton accounting for more than 95% of both the total cultivated area and overall production.

Cotton cultivation regions and sowing

Cotton cultivation in India is spread across ten major states, grouped into three distinct zones: North (Punjab, Haryana, Rajasthan), Central (Maharashtra, Gujarat, Madhya Pradesh), and South (Andhra Pradesh, Telangana, Karnataka, Tamil Nadu). Each zone has unique climatic conditions and soil types, that influence cotton production. These regions vary greatly in their reliance on irrigation and their planting cycles. The details are as follows.

Zone	Estimated area (Mha)	Irrigated area %	Irrigated /Rainfed	Planting Window
North	~1.5	>97%	Irrigated	April – May
Central	68.72	23%	Rainfed	June–July
South	29.93	40%	Rainfed	June– August

Bt cotton, current status

Endotoxin derived from soil bacterium *Bacillus thuringiensis,* genetically modified cotton referred as '*Bt* cotton' introduced in India, Bollgard (Cry1Ac) in 2002 and Bollgard II (Cry1Ac+Cry2Ab) in 2006. It revolutionized pest management covering over 95% of the country's cotton acreage.

ZONE-WISE COTTON PRODUCTION LIMITING FACTORS

1. North India (Punjab, Haryana, Rajasthan)

The North zone is characterized by canal-irrigated, intensive cultivation in alluvial soils.

Biotic factors:

- **Whitefly:** A major sucking pest that acts as a vector for the Cotton Leaf Curl Virus (CLCuV), a devastating disease in this region.
- **Cotton jassid:** A regular pest was seen in high numbers during 2023.
- **Thrips:** Thrips, primarily the species complex dominated by *Thrips palmi* and *Thrips tabaci* have emerged as a significant threat to cotton productivity in recent years.
- **Pink bollworm:** Recent years have seen a resurgence and resistance to Bt toxins.
- **Dusky cotton bug:** The pest has transitioned from a "late-season minor pest" to a significant concern, particularly due to changes in cropping patterns and the extended stay of cotton in the fields and godowns.
- **Leaf spots:** *Corynespora cassicola* has now emerged as major leaf spot disease in addition to *Alternaria* leaf spot, *Myrothecium* leaf spot, as minor during early humid conditions.
- **Boll rot complex:** Boll rot complex emerged as a new threat.
- **Root rot:** Primarily affects cotton in the alluvial soils of Punjab and Rajasthan.
- ***Fusarium* wilt:** Initially affecting *Desi* cotton, however, recent evidence shows that wilt emergingly affecting Upland cotton and its severity is increasing with and without nematode infestation
- **Root knot nematode:** In the last one decade root knot nematode problem has been increasing in Upland cotton which is further enhancing the wilt problem especially in Haryana and Rajasthan

Abiotic factors:

- **Heat stress:** Extremely high temperatures during the early growth and flowering stages can impair photosynthesis and boll retention.
- **Salinity:** High soil and groundwater salinity in parts of South Punjab and Rajasthan limits plant vigour.
- **Late season rains:** Can lead to boll rot and lower lint quality during the harvest period.
- **Parawilt:** Increasing in the area under high rice-wheat cropping systems and poor soil conditions

2. Central India (Maharashtra, Gujarat, Madhya Pradesh, Odisha)

This zone represents the largest cotton-growing area, predominantly rainfed and characterized by black (vertisol) soils.

Biotic factors:

- **Pink bollworm:** This is the most critical biological threat, where the pest has developed severe resistance to Cry toxins.
- **Sucking pest complex:** Includes high infestations of Aphids, Jassids, and Thrips, especially during the vegetative stage.
- **Bacterial blight and Grey mildew:** These diseases thrive in the humid conditions following the monsoon.
- **Boll rot complex:** Boll rot complex emerged as a new threat.
- **Leaf spots:** *Corynespora* has now emerged as a major leaf spot disease in addition to *Alternaria* leaf spot, *Myrothecium* leaf spot, *Phomopsis* leaf spot blight as minor during early humid conditions.
- **Grey mildew:** Earlior it us used to be the late season disease in *Desi* cotton is now emerging as mid and late season disease, causing severe defoliation both in Upland and *Desi* cotton
- ***Fusarium* wilt:** Initially affecting *Desi* cotton, however, recent evidence shows that wilt is affecting Upland cotton with and without nematode infestation.
- **Root knot nematode:** In the last one decade root knot nematode problem has been increasing in Upland cotton, which is further enhancing the wilt problem in some light soil pockets of Gujarat and Maharashtra.
- **Parawilt:** Increasing in the area under high water logging and poor soil conditions.

Abiotic factors:

- **Drought stress:** Since much of the production is rainfed, erratic monsoons or "dry spells" during the flowering stage significantly lower yields.
- **Waterlogging:** Heavy clay soils are prone to poor drainage during excessive rainfall, causing physiological wilting.
- **Soil nutrient depletion:** Declining soil organic carbon due to continuous cropping is a growing concern.

3. South India (Telangana, Andhra Pradesh, Karnataka, Tamil Nadu)

The South zone features diverse soil types (red, black, and mixed) and varies between rainfed and irrigated conditions.

Biotic factors:

- **Sucking pests:** Mirid bugs and Tea mosquito bugs are more prevalent.
- **Stem weevil:** A specific pest of concern in South India that damages the main stem of the plant.
- ***Alternaria* leaf spot:** Caused by *Alternaria macrospora* and concurrently by *Alternaria alternata* remains a major foliar fungal disease of economic significance.
- **Leaf spots:** *Corynespora* has now emerged as major leaf spot disease in addition to

Alternaria leaf spot. Common in the humid environments of Karnataka and Tamil Nadu.

- **Grey mildew:** Earlier it used to be the late season disease in *Desi* cotton is now emerging as mid and late season disease causing severe defoliation both in upland and *Desi* cotton.
- **Leaf rust:** Rust is now emerging as a major disease, its incidence takes place during mid season compared to late season, especially in Andhra Pradesh.
- **Root rot:** Primarily affects cotton in Tamil Nadu.
- **Tobacco streak virus:** Tobacco Streak Virus (TSV), which causes Cotton Necrosis Disease, has emerged as a major biotic constraint. It is now considered a significant threat due to high incidence rates in popular Bt cotton hybrids and its unique transmission mechanism involving the weed *Parthenium hysterophorus*.

Abiotic factors:

1. **High humidity:** Encourages fungal pathogens and boll rot.
2. **Moisture stress:** Variability in the northeast and southwest monsoons causes periodic drought in the rainfed belts of Karnataka and Telangana.
3. **Soil acidity:** Found in certain red soil regions, which can limit the availability of essential nutrients like phosphorus.

ZONE- WISE PEST STATUS ON COTTON

Ubiquitous threats: Pests like the pink bollworm, jassids, whiteflies, aphids, and thrips maintain major status across all three zones, requiring consistent monitoring and integrated management.

Regional specifics: The South zone faces unique challenges from the mirids, Tea Mosquito Bug and Stem weevil, which are largely absent or negligible in the North and Central zones.

Dusky cotton bug: While it is a minor concern in the Central and South zones, it remains a major pest in the North zone, particularly during boll opening stage.

Bollworm transition: Since the widespread adoption of Bt cotton, the Cotton bollworm and Spotted bollworm have generally been relegated to minor status, though the pink bollworm has successfully developed resistance and regained major status in all the three cotton zones of India (Table 1)

Table 1. Zone -wise Pests of cotton and their status in cotton growing zones

S.No	Name of pest	Zone-wise pest status on cotton		
		North	Central	South
	Bollworms			
1.	Pink bollworm, *Pectinophora gossypiella* (Saunders)	Major	Major	Major
2.	Cotton bollworm, *Helicoverpa armigera* (Hubner)	Minor	Minor	Minor
3.	Spotted bollworm, *Earias insulana* (Boisduvel)	Minor	Minor	Minor
4.	Spiny bollworm, *Earias vittella* (Fab.)	Minor	Minor	Minor
	Sucking pests			
5.	Cotton jassid, *Amrasca biguttula biguttula* (Ishida)	Major	Major	Major

S.No	Name of pest	Zone-wise pest status on cotton		
		North	Central	South
6.	Whitefly, *Bemisia tabaci* (Gennadius)	Major	Major	Major
7.	Cotton aphid, *Aphis gossypii* Glover	Major	Major	Major
8.	Thrips, *Thrips Palmi* Karny, *Thrips tabaci* Lind	Major	Major	Major
9.	Cotton mealybug, *Phenacoccus solenopsis* Tinsley	Minor	Minor	Minor
10.	Papaya mealybug, *Paracoccus marginatus* Williams and Granara de Willink	Minor	Minor	Minor
11.	Indian cotton mirid bug, *Creontiades biseratense* (Distant)	Minor	Minor	Major
12.	Green Mirid, *Campylomma livida* Reuter	Minor	Minor	Minor
13.	Mirid, *Hyalopeplus lineifer* Walker	Minor	Minor	Minor
	Other pests			
14.	Tobacco caterpillar, *Spodoptera litura* (Fabricius)	Minor	Minor	Minor
15.	Tea mosquito bug, *Helopeltis theivora* Waterhouse	-	-	Major
16.	Tea mosquito bug, *Helopeltis bradyi* Waterhouse	-	-	Minor
17.	Tea mosquito bug, *Helopeltis antonii* Sign.	-	-	Minor
18.	Stem weevil, *Pempherulus affinis* (Faust)	-	-	Major
19.	Red cotton bug, *Dysdercus cingulatus* Fab.	Minor	Minor	Minor
20.	Dusky cotton bug, *Oxycarenus hyalinipennis* (Costa)	Major	Minor	Minor
21.	Cotton grey weevil, *Myllocerus maculosus* Desb.	Minor	Minor	Minor
22.	Chafer beetle, *Oxycetonia versicolor* (Fabricius)	Minor	Minor	Minor

CROP-STAGE WISE OCCURRENCE OF COTTON PESTS

The cotton crop is highly susceptible to various biotic stresses across all growth stages. Its pest complex transitions from sap-sucking insects during early vegetative phases to destructive bollworms during the reproductive and maturity phases. The tables below detail the chronological progression of these pests across three cotton growing zones of India (Tables 2–4).

Table 2: Crop stage-wise pest incidence and primary impact in North zone

Crop Stage	Dominant Pests	Risk Level	Primary impact
1. Germination & Seedling (1–20 Days)	Thrips	Low	Low number not much impact
	Aphid	Low	Low number not much impact
	Cotton Jassid	Low	Low number not much impact
	Whitefly	Low	Low number not much impact
2. Vegetative growth (20–45 Days)	Cotton jassid	High	Marginal yellowing and downward curling
	Aphid	Low	Upward curling and sticky honeydew
	Whitefly	High	Sticky leaf, virus transmission, leaf enation
	Thrips	Low	Silvery patches on leaves, upward curling
	Spotted bollworm	Low	Drying of terminal shoots in non-*Bt*
	Cotton bollworm	Low	Damaged squares in non *Bt*
	Pink bollworm	Low	Initiation of egg laying
	Cotton mealybug	Low	Not much impact

Crop Stage	Dominant Pests	Risk Level	Primary impact
3. Squaring (Pre-flowering) (45–70 Days)	Pink bollworm	Critical	Rosette flower appearance
	Cotton bollworm	Less	Flared and dropped squaresin non-*Bt*
	Spotted bollworm	Low	Flared up squares
	Cotton jassid	High	Marginal yellowing and downward curling
	Aphid	High	Upward curling and sticky honeydew
	Whitefly	High	Sticky leaf, virus transmission, leaf enation
	Thrips	High	Silvery patches on leaves, upward curling
	Cotton mealybug	Low	Loss of vigour, photosynthesis affected, growth of sooty mold
4. Flowering & boll setting (70–120 Days)	Pink bollworm	Very high	Rosette flowers, sealed entry holes on green bolls, moth catches in pheromone traps, stained lint
	Cotton bollworm	Less	Flared up squares, squares shedding, large circular holes with visible frass on non-Bt
	Spotted bollworm	Less	Flared up squares, square shedding, large circular holes with visible frass on non Bt
	Whitefly		Sticky leaf, growth of black sooty mold, virus transmission, leaf enation, stunted growth
	Cotton jassid	High	Marginal yellowing and downward curling, hopperburn, stunted growth, less fruiting
	Aphid	High	Upward curling and sticky honeydew, growth of black sooty mold
	Thrips	High	Silvery patches on leaves, upward curling, stunted growth, and fewer fruiting bodies
	Dusky cotton Bug	Very high	Nymphs and adults suck sap from the seed and reducing oil content and germination
	Cotton mealybug	Low	Loss of vigour, photosynthesis affected, growth of sooty mold
5. Boll development/ Maturity (120–150 Days)	Pink bollworm	Very high	Round exit holes on carpel walls; premature or partial boll opening; lint quality degradation, less seed, oil content lower down
	Cotton bollworm	Less	Large circular holes with visible frass on non-Bt
	Spotted bollworm	Less	Large circular holes with visible frass on non-Bt
	Cotton jassid	High	Marginal yellowing and downward curling, hopperburn, stunted growth, less fruiting
	Aphid	High	Upward curling, sticky honeydew, growth of black sooty mold
	Whitefly	High	Sticky leaf, growth of black sooty mold, virus transmission, leaf enation, stunted growth, less bolls
	Thrips	High	Upward curling, stunted growth, fewer fruiting bodies
	Dusky cotton bug	Very high	Nymphs and adults suck sap from the seed and lower oil content and germination
	Cotton mealybug	Low	Loss of vigour, photosynthesis affected, growth of sooty mold, and reduced yield

Crop Stage	Dominant Pests	Risk Level	Primary impact
Harvesting (150–180 Days)	Pink bollworm	Very high	Round exit holes on carpel walls; premature or partial boll opening; lint quality degradation, less seed, oil content lower down
	Cotton bollworm	Less	Large circular holes with visible frass on non-*Bt*
	Spotted bollworm	Less	Large circular holes with visible frass on non-*Bt*
	Cotton jassid	Less	Hopperburn, stunted growth, less fruiting
	Aphid	High	Sticky honeydew, growth of black sooty mold
	Whitefly	High	Sticky leaf, growth of black sooty mold, virus transmission, leaf enation, stunted growth, fewer bolls
	Thrips	Less	Stunted growth, fewer bolls
	Dusky cotton bug	Very high	Nymphs and adults suck sap from seed and lower down the oil content and germination, causing obnoxious odour, and discomfort to labour
	Cotton mealybug	Low	Loss of vigour, photosynthesis affected, growth of sooty mold, reduced yield

Table 3: Crop stage-wise pest incidence and primary impact in Central zone

Crop stage	Dominant pests	Risk level	Primary impact
1. Germination & Seedling (1-20 Days)	Thrips	Low	Low number not much impact
	Aphid	Low	Low number not much impact
	Cotton Jassid	Low	Low number not much impact
	Whitefly	Low	Low number not much impact
2. Vegetative growth (20–45 Days)	Cotton jassid	Low	Marginal yellowing and downward curling
	Aphid	Low	Upward curling and sticky honeydew
	Whitefly	Low	Loss of vigour
	Thrips	Low	Silvery patches on leaves
	Spotted bollworm	Low	Drying of terminal shoots in non-*Bt*
	Cotton bollworm	Low	Flared up squares in non-*Bt*
	Pink bollworm	Low	Initiation of egg laying
	Cotton mealybug	Low	Loss of vigour
3. Squaring (Pre-flowering) (45–70 Days)	Pink bollworm	Critical	'Rosette flower' appearance
	Cotton bollworm	Low	Flared up and dropped squares in non-*Bt*
	Spotted bollworm	Low	Flared up squares
	Cotton jassid	High	Marginal yellowing and downward curling

Crop stage	Dominant pests	Risk level	Primary impact
	Aphid	High	Upward curling, sticky honeydew
	Whitefly	Low	Loss of vigour
	Thrips	High	Silvery patches on leaves, upward curling
	Cotton mealybug	Low	Loss of vigour
4. Flowering & Boll Setting (70–120 Days)	Pink bollworm	Very High	Rosette flowers, sealed entry holes on green bolls, moth catches in pheromone traps, stained lint
	Cotton bollworm	Low	Flared up squares, square shedding, large circular holes with visible frass on non-*Bt*
	Spotted bollworm	Low	Flared up squares, square shedding, large circular holes with visible frass on non-*Bt*
	Whitefly	Low	Loss of vigour, sticky leaf
	Cotton jassid	High	Marginal yellowing and downward curling, hopperburn, stunted growth, and less fruiting
	Aphid	Low	Sticky honeydew, growth of black sooty mould
	Thrips	High	Silvery patches on leaves, upward curling, stunted growth, and fewer fruiting bodies
	Dusky cotton bug	Low	Nymphs and adults suck sap from the seed, lowering the oil content and germination.
	Cotton mealybug	Low	Loss of vigour, photosynthesis affected, sooty mold growth and reduced yield.
5. Boll development/ Maturity (120–150 Days)	Pink bollworm	Very high	Round exit holes on carpel walls, premature or partial boll opening, lint quality degradation, less seed, oil content lower down
	Cotton bollworm	Low	Large circular holes with visible frass on non-*Bt*
	Spotted bollworm	Low	Large circular holes with visible frass on non-*Bt*
	Whitefly	Low	Stunted growth
	Cotton jassid	Less	hopperburn, stunted growth, fewer bolls
	Aphid	High	Upward curling and sticky honeydew, growth of black sooty mold
	Thrips	low	Stunted growth, less fruiting bodies
	Dusky cotton bug	Less	Nymphs and adults suck sap from seed and lower down oil content and germination
	Cotton mealybug	Low	Loss of vigour and photosynthesis affected due to growth of sooty mold, reduced yield
Harvesting (150–180 Days)	Pink bollworm	Very high	Round exit holes on carpel walls; premature or partial boll opening; lint quality degradation, less seed, low oil content
	Cotton bollworm	Low	Large circular holes with visible frass on non-*Bt*
	Spotted bollworm	Low	Large circular holes with visible frass on non-*Bt*
	Cotton jassid	Low	Hopperburn, stunted growth, fewer bolls

Crop stage	Dominant pests	Risk level	Primary impact
	Aphid	High	Sticky honeydew, growth of black sooty mold
	Whitefly	Less	Stunted growth, fewer bolls
	Thrips	Low	Stunted growth, fewer bolls
	Dusky cotton bug	Low	Nymphs and adults suck sap from the seed and lower the oil content and germination, causing obnoxious odour and discomfort to labour
	Cotton mealybug	Low	Loss of vigour and photosynthesis affected due to growth of sooty mold, reduction in yield.

Table 4 : Crop stage-wise pest incidence and primary impact in South zone

Crop Stage	Dominant Pests	Risk Level	Primary impact
1. Germination & seedling (1 – 20 Days)	Thrips	Low	Low number not much impact
	Aphid	Low	Low number not much impact
	Cotton jassid	Low	Low number not much impact
	Whitefly	Low	Low number not much impact
2. Vegetative growth (20 – 45 Days)	Cotton jassid	Low	Marginal yellowing and downward curling
	Aphid	Low	Upward curling and sticky honeydew
	Whitefly	Low	Loss of vigour
	Thrips	Low	Silvery patches on leaves
	Spotted bollworm	Low	Drying of terminal shoots in non-*Bt*
	Cotton bollworm	Low	Flared up squares in non-*Bt*
	Pink bollworm	Low	Initiation of egg laying
	Stem weevil	High	The plant collapses due to stem cutting
	Cotton mealybug	Low	Loss of vigour
	Papaya mealybug	Low	Loss of vigour
3. Squaring (Pre-flowering) (45–70 Days)	Pink bollworm	Critical	'Rosette flower' appearance
	Cotton bollworm	Low	Flared up and dropped squares in non-*Bt*
	Spotted bollworm	Low	Flared up squares in non-*Bt*
	Cotton jassid	High	Marginal yellowing and downward curling
	Aphid	High	Upward curling, sticky honeydew
	Whitefly	Low	Loss of vigour
	Thrips	High	Silvery patches on leaves, upward curling
	Stem weevil	High	The plant collapses due to stem cutting
	Mirids	Low	Both nymphs and adults suck sap from developing squares, turning them yellow or brown and eventually causing them to drop off.
	Tea mosquito bug	High	Necrotic patches on leaves and stems.
	Cotton mealybug	Low	Loss of vigour
	Papaya mealybug	Low	Loss of vigour
4. Flowering & boll setting (70–120 Days)	Pink Bollworm	Very high	Rosette flowers, sealed entry holes on green bolls, moth catches in pheromone traps, stained lint
	Cotton bollworm	Low	Flared up squares, square shedding, large

Crop Stage	Dominant Pests	Risk Level	Primary impact
			circular holes with visible frass on non-*Bt*
	Spotted bollworm	Low	Flared up squares, square shedding, large circular holes with visible frass on non-*Bt*
	Whitefly	Low	Loss of vigour, sticky leaf
	Cotton jassid	High	Marginal yellowing and downward curling, hopper burn, stunted growth, fewer fruiting bodies
	Aphid	Low	Sticky honeydew, growth of black sooty mold
	Thrips	High	Silvery patches on leaves, upward curling, stunted growth, fewer fruiting bodies
	Dusky cotton bug	Low	Nymphs and adults suck sap from the seed, lowering the oil content and germination
	Stem weevil	High	The plant collapses due to stem cutting
	Mirids	High	Both nymphs and adults suck sap from developing squares, turning them yellow or brown and eventually causing them to drop off. Feeding on bolls results in Necrotic Lesions and stained lint.
	Tea mosquito bug	High	Necrotic patches on leaves, stems and bolls, shrivelling squares and tender bolls
	Cotton mealybug	Low	Loss of vigour, photosynthesis affected due to growth of sooty mould, reduction in yield
	Papaya mealybug	Low	Loss of vigour, photosynthesis affected due to growth of sooty mold, reduction in yield
5. Boll Development/ Maturity (120–150 Days)	Pink bollworm	Very High	Round exit holes on carpel walls, premature or partial boll opening, lint quality degradation, less seed, low oil content
	Cotton bollworm	Low	Large circular holes with visible frass on non-*Bt*
	Spotted bollworm	Low	Large circular holes with visible frass on non-*Bt*
	Whitefly	Low	Stunted growth
	Cotton jassid	Less	Hopperburn, stunted growth, fewer fruiting bodies
	Aphid	High	Upward curling and sticky honeydew, growth of black sooty mold
	Thrips	low	Stunted growth, less fruiting bodies
	Dusky cotton bug	Less	Nymphs and adults suck sap from seed and lower the oil content and germination
	Stem weevil	Low	The plant collapses due to stem cutting
	Mirids	High	Both nymphs and adults suck sap from developing squares, turning them yellow or brown and eventually causing them to drop off, feeding on bolls results in Necrotic Lesions and stained lint
	Tea mosquito bug	High	Necrotic patches on leaves, stems and bolls shrivelling squares, and tender bolls

Crop Stage	Dominant Pests	Risk Level	Primary impact
	Cotton mealybug	Low	Loss of vigour, photosynthesis affected due to growth of sooty mold, reduction in yield
	Papaya mealybug	Low	Loss of vigour, photosynthesis affected, sooty mold growth, reduced yield
Harvesting (150–180+ Days)	Pink bollworm	Very High	Round exit holes on carpel walls; premature or partial boll opening; lint quality degradation, less seed, oil content lower down
	Cotton bollworm	Low	Large circular holes with visible frass on non-Bt
	Spotted bollworm	Low	Large circular holes with visible frass on non-Bt
	Cotton jassid	Low	Hopperburn, stunted growth, fewer fruiting
	Aphid	High	Sticky honeydew, growth of black sooty mould
	Whitefly	Less	Stunted growth, fewer bolls
	Thrips	Low	Stunted growth, fewer bolls
	Dusky cotton bug	Low	Nymphs and adults suck sap from the seed and lower the oil content and germination, obnoxious odour and discomfort to labour
	Stem weevil	Low	The plant collapses due to stem cutting
	Mirids	Low	Feeding on bolls results in necrotic lesions and stained lint
	Tea mosquito bug	Low	Necrotic patches on bolls, poor opening of bolls, secondary infection of pathogens loss of yield
	Cotton mealybug	Low	Loss of vigour, photosynthesis affected due to growth of sooty mold, resulting in a reduction in yield
	Papaya mealybug	Low	Loss of vigour and photosynthesis affected due to sooty mold growth, reduced yield

INSECT PESTS AND MANAGEMENT STRATEGY

I. Bollworms

1. PINK BOLLWORM

National importance: Pink bollworm (PBW), *Pectinophora gossypiella* (Saunders) (Lepidoptera: Gelechidae), widespread infestation was observed in Gujarat, Maharashtra, Andhra Pradesh, Telangana, Karnataka and Madhya Pradesh states starting from 2015. Outbreak of pink bollworm was observed in the 2017–2018 season in Central and South India while during 2023–24 in North India. Now the pest is causing significant damage to cotton production in all the three cotton zones of India.

Economic impact: The quality of lint deteriorated due to the presence of larvae and pest induced staining. Pink bollworm causing alarming yield losses of 20–30%.

Nature of damage: The "Rosette flower" is the typical symptom of PBW infestation during the early reproductive phase of cotton growth. The larva enters the developing boll through

the rind and feeds primarily on the seeds. In younger bolls, the entire contents can be destroyed; however, in older bolls, larvae typically consume multiple developing seeds. As the larvae feed, they cut and stain the lint, resulting in severe loss of quality. Furthermore, infested bolls may open prematurely, leaving them vulnerable to fungal infections. If infested seeds are used for sowing, germination is significantly reduced. Ultimately, decreasing overall weight, vitality, and oil content in seed cotton.

Rosette flower

Exit hole

Infested green boll

Deformed open boll

Period of occurrence: Infestation begins during the squaring-to-flowering stages, with intensity increasing as the season progresses. Generally, peak infestation of the pink bollworm occurs between September to October in North India, and between October and December in Central and South India.

***Bt* resistance:** The transgenic cotton producing cry insecticidal proteins from a soil bacterium *Bacillus thuringiensis* (*Bt*) have been deployed in India with single gene Cry 1Ac in 2002 followed by dual gene construct (Cry 1Ac + Cry 2Ab) Bollgard II in 2006. One of the most significant worries associated with the use of *Bt*-toxin-based pest management technologies is the risk of insects evolving resistance to Cry toxins as the laboratory selection experiments have shown a great potential for resistance development in many insects (Ferre

and Rie, 2002). In India, survival of PBW population on single-gene Bt cotton was noticed in Gujarat during 2008 to Cry1Ac (Dhurua and Gujar, 2011; Fabrick *et al*., 2014). Subsequently, field evolved resistance against both genes, Cry1Ac and Cry2Ab was reported from India which reports a dramatic increase in resistance ratios (RR) in Central and South Indian field populations of pink bollworm from mean RR of 47.12 (Range 18–121) in 2013 to mean RR of 1387 (Range 704–2060) in 2017 for Cry 1Ac and mean RR of 5.40 (Range 1–31) in 2013 to mean RR of 4196 (Range 1306–9366) in 2017 for Cry 2Ab (Naik et al., 2018). Laboratory selection of field-resistant strain reported reduced susceptibility to Cry1Ac by >2000-fold (Mohan et al., 2016). Recent studies by Jambagi et al. (2023) confirmed continued resistance development across South Indian cotton-growing regions as well. Agrawal et al., (2020) identified 1,741 differentially expressed genes between susceptible and resistant strains, with down-regulation of known *Bt* receptor genes (APN, ABCA, cadherin) and up-regulation of detoxification enzymes (cytochrome P450, GST, carboxylesterase). Subsequently, PBW infestations were observed in North India starting in 2018. This resurgence indicates the development of significant resistance to Cry toxins, signalling a potential failure of current technology. Over the last decade, the widespread infestation of PBW on Bt cotton has become a major concern for cotton growers across all three zones of India (Fand et al., 2019; 2025; Kumar et al., 2020; 2025; Nagrare et al., 2025).

Mark of identification:

- **Eggs :** The eggs are very small, pearly shaped, microscopic and yellow in color measuring approximately 0.42±0.02 mm in length and 0.19±0.01 mm in width. The shell is finely sculptured with distinct longitudinal lines. Eggs are laid either singly or in small clusters embedded inside the brackets of squares and under the calyx of small bolls.
- **Larva :** First two instars are creamy-white, while from third instar pink colour develops. Full grown larvae measured about 10.20±0.66 mm in length, possess a dark brown to black head.
- **Pupa :** A pupa measures approximately 7.32±0.31 mm in length. Pupation occurs within a thin, silken cocoon located in the lint, the soil, or the *kapas* (seed cotton). The pupae are initially light brown but gradually transition to a dark brown hue as development proceeds.
- **Adult :** Male adult moths measure 6.75±0.22 mm in length, female moth measure 7.21±0.21 in length and both are greyish-brown with distinct blackish bands on the forewings; the hind wings are a contrasting silvery grey. While moths emerge from their pupae during the morning or evening, they are primarily nocturnal, remaining hidden among soil debris or within ground cracks during the day.

Life cycle: A single adult female lays about 203.73±38.83 eggs in a life time. Egg incubation period 05.33±0.21days, larval period 21.50±1.04days, pupal period 07.60±0.57 days, adult female longevity 15.74±1.63 days, adult male longevity 11.12±1.18 days, life cycle egg to adult 34.43±0.61 days however, varies depending on prevailing temperature and humidity (Fand et al., 2020; 2021; Peddu et al., 2020; Rakhesh et al., 2026) (Fig 1).

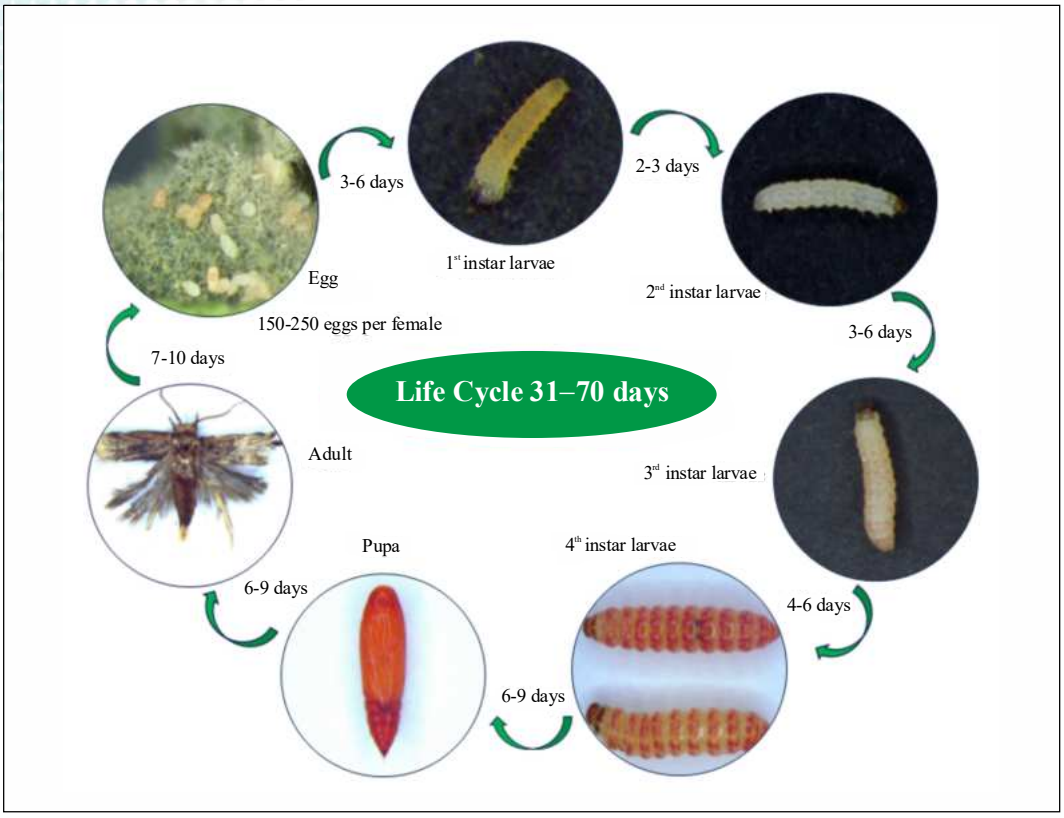


Fig 1. Life cycle of pink bollworm

Pest surveillance:

i) **Pheromone trap-based monitoring:** This is the most common method for tracking adult moth activity. It uses a synthetic sex pheromone (Gossyplure) to attract male moths. Funnel traps or Sleeve traps are generally preferred. Traps should be installed at the onset of the squaring stage (approximately 40–45 days after sowing of crop). Two traps per acre, positioned at least 15–30 cm above the crop canopy are recommended. As the cotton grows, the height of the trap must be adjusted. Initiate monitoring at 45 days after sowing. Insecticidal sprays should be initiated when pheromone trap catches exceed five per trap per night for three consecutive nights (Fand et al., 2026).

ii) **Field scouting:** Since eggs are microscopic, they are not easily visible and young larvae are hidden inside the green bolls, farmers must perform "destructive sampling" to assess the actual damage within the bolls. Randomly select 20 green bolls per acre (approximately 15–20 days old). Look for "Rosette flowers".

Economic threshold: 5–10% rosette flowers in the early reproductive phase, trap catches 5–8 moths per night for three consecutive nights, 5–10% infestation (e.g., 1–2 out of 20 green bolls containing live larvae or showing internal damage).

Management strategy:

I. Pre-sowing and planting phase

- **Crop rotation:** Practice regular crop rotation to break the PBW life cycle.
- **Seed procurement:** Purchase authentic Bt-cotton hybrids or varieties from authorized dealers.
- **Variety selection:** Opt for short-to-medium duration Bt-cotton hybrids or varieties recommended for the region.
- **Sowing window:** Ensure timely sowing and strictly avoid pre-season sowing, as early crops are highly susceptible to PBW.
- **Optimal spacing:** Adhere to the recommended zonal spacing to maintain the ideal plant population.

II. Nutrient and field management

- **Judicious fertilization:** Avoid excessive doses of nitrogenous fertilizers (e.g., urea) as basal or top dressing to prevent succulent overgrowth, which attracts pests.
- **Historical monitoring:** Fields that suffered heavy PBW damage in the previous season should be monitored with increased vigilance.

III. Monitoring and economic threshold

- **Pheromone traps:** Install pheromone traps at a density of 2 per acre. Place additional traps near ginneries and stacked cotton stalks to capture suicidal emergence.
- **Field scouting:** Inspect flowers for larvae. Physically remove and destroy rosette flowers immediately. Randomly pluck and dissect 20 green bolls per acre from different plants to check for internal damage or larvae.

IV. Chemical control and safety

- **Insecticide selection:** Use only label-claim insecticides. Never use tank mixtures of different agrochemicals or unapproved insecticide blends.
- **Pyrethroid restrictions:** Strictly avoid spraying synthetic pyrethroids before 120 days to prevent secondary outbreaks of whiteflies and aphids.
- **Safety protocols:** Always wear protective aids (gloves, masks, etc.) when handling and applying chemical pesticides.

V. Harvest and post-harvest sanitation

- **Separate picking:** Harvest clean cotton and infested cotton separately. Market the clean cotton and avoid storing stained or infested seed cotton in godowns.
- **Crop duration:** Terminate the crop as early as economically feasible. Do not extend the cotton crop beyond 180 days to prevent late-season pest buildup. For this purpose, give last irrigation by end of September in case of North zone. It would reduce bollworms damage and their carryover to the next cropping season.
- **Animal grazing:** Allow animals to graze in the field after picking to reduce the carryover of bollworms.
- **Stalk management:** Stack cotton stalks away from the field vertically. Do not stack

stalks in the field. If possible, shredding of cotton stalks in soil is advisable. Clean the field of residual stalks and partially opened bolls immediately after harvest. Stacks should be kept away from cultivation areas and consumed (as fuel or otherwise) before March. In the North zone, stalks retained after March 30th must be beaten to dislodge unopened bolls and covered securely with mosquito nets or plastic sheets to prevent moth escape. Destroy all remaining trash and residues.

Crop growth stage: 0–60 DAS

- At 45 DAS, install pheromone traps @ 5 per ha.
- Install AI smart pheromone trap @ 1 per village on community basis.
- Spray NSKE 5% + Azadirachtin 0.15 EC @ 5 mL /L or NSKE/neem oil-based formulation 5 mL /L (300 or 1500 ppm) + 1.0 mL surfactant (Initial 1–2 sprays). (NSKE 25L + Azadirachtin 0.15 EC @ 2.5 L + 0.5 L surfactant per ha). Use 150–200 L of water /acre or 375–500 L/ ha for dilution of the insecticides.

Crop growth stage: 61–90 DAS

- Observe for rosette flowers, pluck and destroy them.
- At boll formation stage, farmers are advised to inspect the presence and damage of pink bollworm by plucking and dissecting 20 green bolls from different plants randomly (one boll per plant). If ETL crossed i.e. >10% damaged flowers (Rosette flowers) or 5–10% damaged green bolls (at least 1–2 out of 20 bolls having white or pink larvae or exit holes) and or 5–8 moths catch per pheromone trap/AI-smart pheromone trap for consecutive 3 days, spray Profenofos 50% EC @ 30 mL/10L (1500 mL/ha) or Emamectin benzoate 5% SG @ 5 g/10L (250 g/ha) or Spinetoram 11.70 SC @ 9 mL/10L (450 mL/ha) or Indoxacarb 14.5% SC @ 10mL/10L (500mL/ha) or Chlorpyrifos 20 % EC @ 25mL/10L (1250 mL/ha). (10L= Ten liter of water)

Crop growth stage: 91–120 DAS

- If ET crossed, 5–10% damaged green bolls and / or 5–8 moths catch per pheromone trap/AI-smart pheromone trap for consecutive 3 days, release parasitoid *Trichogrammatoidea bactrae* @ 60000 per acre.
- Or spray cotton crop with Profenofos 50%EC @ 30 mL/10L (1500 mL/ha) or Emamectin benzoate 5 SG @ 5 g/10L (250 g/ha) or Spinetoram 11.70 SC @ 9 mL/10L (450 mL/ha) or Indoxacarb 14.5% SC @ 10 mL/10L (500mL/ha) or Chlorpyrifos 20 % EC @ 25 mL/10L (1250 mL/ha).
- In addition to above, Fipronil 5% EC @ 40 mL/10L (2000 mL/ha) is suggested for Central and South India.

Crop growth stage: >120 DAS

- If ET crossed, 5–10% damaged green bolls and or 5–8 moths catch per pheromone trap/AI-smart pheromone trap for consecutive 3 days, spray Cypermethrin 10% EC @ 10–15 mL/10L (550–760 mL/ha) or Cypermethrin 25% EC @ 4–6 mL (160–280 mL/ha) or Lambda cyhalothrin 5% EC @ 10 mL/10L (500 mL/ha) or Deltamethrin 2.8

EC @ 10 mL/10L (500 mL/ha) or Fenpropathrin 10% EC @ 15–20 mL/10L (750-1000 mL/ha) or Fenvalerate 20% EC @ 10 mL/10L (500 mL/ha) or Alphacypermethrin 10% SC @ 6mL/10L (250-300 mL/ha).

Functioning of AI Smart Pheromone Trap and mobile based applications developed by the ICAR-CICR

Digital technologies are transforming cotton pest management from reactive pesticide-based approaches to proactive intelligence-based integrated pest management systems. Adoption of digital tools in cotton ecosystems can substantially improve pest forecasting, reduce unnecessary pesticide applications, support sustainable agriculture and strengthen climate-resilient crop protection strategies.

Artificial Intelligence (AI) smart pheromone trap and mobile based applications developed by the ICAR-CICR have emerged as a promising tool for real-time surveillance of major cotton pests, particularly pink bollworm. By enabling automated pest detection, rapid data transmission and timely advisories, these systems enhance the efficiency, accuracy, and scalability of pest monitoring programmes.

AI Smart Pheromone Trap

The AI Smart pheromone trap has been deployed for the real-time monitoring of PBW in Punjab state during the crop season 2024–2025. Using automated real-time data, daily alerts and weekly advisories on PBW damage and management strategies were issued to stakeholders. Over 4 lakh voice messages in Punjabi were sent via GSM network to 28,190 cotton growers, with district-specific alerts when trap catches exceeded the economic threshold. PBW control measures were also disseminated through mass media and social media channels for broader farmer outreach.

The implementation of AI driven pest monitoring has significantly improved pest detection, management efficiency, and cost-effectiveness compared to traditional methods. The pilot scale deployment of AI smart traps in the Punjab yielded encouraging results on reduced crop damage due to timely pest alerts and prompt control measures, 38.6% reduction in pesticide use while keeping PBW damage under control and 18.54% increase in yield over conventional methods, highlighting the potential of AI traps to enhance cotton productivity while reducing chemical dependency.

Encouraged by the positive outcomes of the pilot scale deployment of AI enabled pheromone traps at Punjab, the technology was scaled up during the 2025–2026 season to strengthen digital pest surveillance across the North zone. The expanded deployment covered 40 villages distributed across eight major cotton-growing districts in three key cotton-producing states Haryana, Punjab, and Rajasthan. The objective of the scale-up was to

establish a wider network of AI Smart Pheromone Traps capable of providing continuous, real-time monitoring of pink bollworm population dynamics and enabling timely pest management advisories to the cotton growers in the entire North zone of cotton cultivation.

The project combines advanced AI driven pest monitoring, environmental sustainability, and economic benefits, making it a holistic solution for PBW management in cotton farming. By offering a data driven forewarning system, reducing chemical pesticide reliance, and cutting down cultivation costs, it ensures long-term agricultural sustainability, improved farmer livelihood, and environmental conservation.

2. COTTON BOLLWORM

National importance : Cotton bollworm, *Helicoverpa armigera* (Hubner) (Lepidoptera: Noctuidae), is a highly polyphagous and migratory insect pest recognized as a pest of national importance in India. Its wide host range enables continuous survival and multiplication across diverse cropping systems and agro-climatic regions, ranging from irrigated and rainfed plains to high-altitude Himalayan ecosystems. Adult moths are strong nocturnal fliers capable of long-distance migration extending several hundred kilometers, facilitating its rapid dispersal and reinfestation over wide geographical areas. High fecundity of female moths further contributes to severe pest outbreaks. The extensive and indiscriminate use of synthetic insecticides for bollworm management has resulted in the development of resistance to major insecticide groups, including carbamates, cyclodienes, organophosphates, and pyrethroids, thereby increasing management costs and environmental concerns in agricultural ecosystems. Since the introduction of *Bt* Cotton, the pest is under control however, in non *Bt* cotton crop it causes substantial damage.

Economic impact: The larvae primarily damage the reproductive structures of plants, including squares, flowers, and bolls. In cotton, extensive larval feeding on developing bolls reduces both yield and fibre quality, while feeding injuries facilitate the entry of boll rot pathogens, resulting in rotting of damaged bolls and additional crop loss. The pest has become a major bollworm species in almost all cotton-growing regions because of the increasing severity and frequency of infestations. In India, *H. armigera* is responsible for yield losses ranging from 15–50%, with losses reaching up to 40% in non-*Bt* cotton.

Nature of damage: The larvae predominantly damage the reproductive structures of cotton and are considered highly destructive during the flowering and boll formation stages. Initially, young larvae feed on tender leaves and small squares, while later instars bore into squares, flowers and bolls. The larvae typically insert their head and thoracic region into the boll, leaving the posterior body portion outside. Feeding sites are characterized by large circular entry holes surrounded by frass and excreta. Early instar feeding on small squares produces delicate webbing, whereas larger larvae completely consume the internal contents of bolls. Damaged squares exhibit flaring of bracts, and premature shedding. Excessive shedding of buds, squares, and immature bolls is common under severe infestation. A single larva is capable of damaging nearly 30–40 fruiting bodies during its developmental period. Feeding injury also facilitates the entry of boll rot pathogens and secondary microorganisms, resulting in rotting of damaged bolls, deterioration in fibre quality, and substantial yield loss.

Flower bud

Square

Flower

Boll

Period of occurrence: The incidence of *H. armigera* varies seasonally, with damage extending up to November–December. Peak infestation generally coincides with the third and fourth generations during peak squaring. Maximum occurrence is observed from August–October in Northern and Central India and from November–December in Southern regions, particularly under active monsoon conditions.

Resistance to *Bt* and insecticides

a) Insecticide resistance: H. armigera has a documented history of developing resistance to major insecticide groups including organophosphates, carbamates, cyclodienes, and pyrethroids across key agricultural nations like India, China, Pakistan, and Australia. During the pre-*Bt* cotton era of the 1980s and 1990s, widespread resistance to pyrethroids (particularly cypermethrin) escalated dramatically, with resistance levels up to 8,022-fold. Severe pyrethroid resistance was first documented in Andhra Pradesh, India, in 1987. Because the pest easily survived repeated chemical applications, farmers escalated their inputs sometimes exceeding 20 sprays per season. This unsustainable cycle triggered catastrophic crop failures, spiralling production costs, environmental degradation, and the systematic elimination of natural enemies. In response to this crisis, global cotton-growing regions shifted toward robust IPM frameworks. These programs harmonized cultural practices, pheromone monitoring, biopesticides, and conservation of biological control

agents with strict, need-based synthetic insecticide applications. Following these interventions and the subsequent adoption of Bt cotton since 2000, *H. armigera* infestations in cotton ecosystems have declined substantially across India, with populations now rarely breaching economic thresholds.

b) Bt resistance: Transgenic *Bt* cotton introduced in India in 2002 significantly increased cotton productivity and reduced pesticide consumption by nearly 50–60%. However, subsequent studies revealed variable expression of Cry toxins in different plant parts, allowing survival and feeding of *H. armigera* on *Bt* cotton under certain conditions. Evidence of successful survival and reproduction of the pest on *Bt* cotton has also been reported from India. Similar observations were made in the United States, where *Helicoverpa zea*, a closely related species, caused significant boll damage on Bollgard cotton. These findings highlight the need for continuous monitoring and IPM strategy to prevent future pest outbreaks and resistance development. *H. armigera* populations recorded Cry1Ac susceptibility from 0.01 to 0.67 µg/ml, indicating a 67-fold variation during the baseline susceptibility studies (Kranthi et al. 2001). There was an increasing trend in Cry1Ac tolerance 18–119 folds after the introduction of *Bt* cotton in 2002 (Kalia et al., 2006). An unusual field survival and reproduction, following completion of life cycle on BGII cotton was reported from Raichur, India (Ranjith et al., 2010) with consequent studies confirming an increase in the frequency of resistant alleles (Kukanur et al., 2018; Singh & Kukanur, 2021). Studies conducted at ICAR-CICR in 2024–25 clearly show an increasing value of Cry1Ac resistance (Ranging from 0.90–2.90 ppm) with corresponding resistance ratios of 90–290 folds along with mutations in ABCC2 gene in selected populations (Rangaraju et al., 2025).

Mark of identification:

- **Eggs:** Eggs are spherical with a flattened base and possess longitudinal ribs on the chorion, measures approximately 0.42–0.60 mm in length. Freshly laid eggs are creamy white, gradually turning brown before hatching due to embryonic development. Eggs are laid singly on tender leaves, stems, and reproductive structures of cotton plants.
- **Larva:** Newly hatched larvae are translucent yellowish-white with dark brown to black head capsules and prominent thoracic and anal shields. Larval colouration varies from green to fawn yellow or brown depending on age and host diet. Larvae passes through six larval instars, with later instars becoming darker and more prominently patterned. The larvae typically grow to a length of 30–35 mm in their final instar.
- **Pupa :** Pupation occurs in the soil at a depth of 2.5–12.5 cm. Pupae are smooth, brown, and rounded at both ends, with two tapering spines at the posterior end. The larvae typically grow to a length of 30–40 mm in their final instar. The pupa measures approximately 17–21 mm in length.
- **Adult :** Adult moths are stout-bodied and vary in colour from greenish yellow to buff brown with darker brown or blackish markings on the wings. Males are generally lighter brown with a greenish hue, whereas females are comparatively darker. Adult body

length ranges from 17–20 mm with a wing span of approximately 35–41 mm. The moths exhibit nocturnal activity, with peak flight occurring from dusk to midnight, and are capable of long distance dispersal in search of suitable host crops.

Life cycle: *H. armigera* completes its life cycle ranging from 31–49 days depending on environmental conditions. A single female lays an average of 557–739 eggs during her life span of 8–12 days. The egg period lasts for 2–5 days, while the larval period 14–25 days. The larval stage generally consists of six instars, with individual instars lasting about 3–5 days each, followed by a short pre-pupal phase of 2–3 days. Pupal period lasts for 10–16 days (Ali et al., 2009, Gusain et al., 2023) (Fig 2).

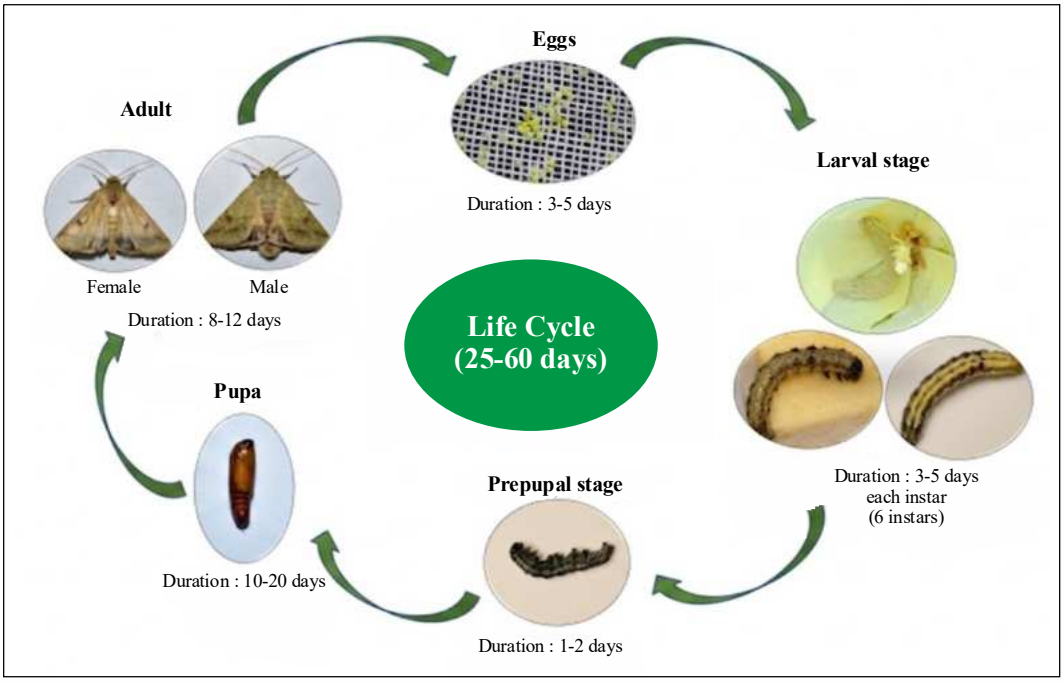


Fig 2. Life cycle of *H. armigera*

Pest surveillance:

i) **Pheromone trap monitoring:** Install pheromone traps @ 5 traps per ha, spaced approximately 50 m apart. Lure should be replaced as per validity. Trapped moths should be removed daily.

ii) **Field scouting:** Monitoring of *H.armigera* should be carried out through regular field scouting. Field observations at 3–5 days intervals are recommended to assess egg and larval populations on terminal leaves, fruiting bodies, and shed plant material for estimating economic threshold.

Economic threshold: 4–5 moths per trap per day or 20% plants with flared squares or one larva per plant or 5–10% damaged fruiting structures.

Management strategy:

Crop growth stage: 0–60 DAS

- **Crop rotation:** Crop rotation should be followed with non-host to break the life cycle.
- **Intercropping:** Intercropping is one of the important components of IPM in sustainable cotton farming. Mixing cotton with crops like pigeon pea, soybean, cowpea, castor, ambadi, and jowar naturally reduces pest incidence by providing vital habitat, food, and shelter for beneficial natural enemies (such as parasitoids, coccinellid beetles, lacewings, and predatory wasps). In Central and South India, recommended intercropping are Cotton + Pigeon Pea: 6:1 or 6:2 row ratio or Cotton + Soybean: 2:4 row ratio. Intercropping is not recommended in North India.
- **Installing pheromone traps:** Pheromone traps should be installed @ 5 traps per ha at 45 DAS.
- **Biological control:** Randomly interplanting trap crops within cotton rows strengthens natural pest management and provides live perches to attract insect eating birds.

Crop growth stage: 61–90 DAS

- **Terminal clipping:** De-topping or clipping terminal shoots, performed 80–120 days after sowing or when plants reach a height of 100–120 cm, offers significant agronomic and pest management benefits such as lowers oviposition (egg-laying) by *H. armigera*, enhances canopy aeration and sunlight penetration, promotes lateral sympodial branching, boosts overall boll development and final crop yield.
- **Mechanical suppression:** Regularly collecting and destroying damaged floral bodies and mature larvae directly interrupts pest life cycles and reduces field populations.
- **Botanical pesticides:** Botanical pesticides, particularly neem-based formulations, are highly effective, eco-friendly options for managing *H. armigera* and other cotton pests. These botanicals naturally reduce infestation levels by acting as antifeedants, repellents, oviposition deterrents, and insect growth regulators. Azadirachtin of 0.15%, 0.3% (3,000 ppm), 0.03% neem oil-based products, and 5% neem extract concentrate can be applied at dose 5.0 L/ha, depending on pest pressure and product potency. Neem Seed Kernel Extract (NSKE) can be applied as a protective spray at 5% concentration. Spray formulated Neem Oil @ 5 mL/L of water. Dashparni extract can be applied as a protective spray at 10% concentration. Karanj oil formulations at 1% concentration are also effective.
- **Bird predation :** Installing 8–10 T-shaped bird perches per ha approximately 90 days after sowing encourages insectivorous birds to settle in the field. These natural predators actively suppress caterpillar populations, providing a cost effective, eco-friendly pest management solution.
- **Biological control:** Augmentative releases of *Chrysoperla* eggs or larvae @ 10,000/ha and *Trichogramma* parasitoids @ 1,50,000/ha/week or 60,000 parasitized eggs per acre at weekly intervals during 45–100 DAS. HaNPV is highly effective against early instar larvae. Apply 250 larval equivalents (LE)/ha or 2,700 mL/ha. *Bacillus thuringiensis* formulations of *Bt* var. *kurstaki* are suggested. Depending on formulation and potency,

apply at 0.5–2.5 kg/ha or 750–1,000 mL/ha. Entomopathogenic fungi species such as *Beauveria bassiana*, *Metarhizium anisopliae*, and *Nomuraea rileyi* offer effective control. Apply at 5 g/L of water, or 2 kg/ha diluted in 400–500 liters of water. Insecticide applications should be avoided for at least one week before and after release of biocontrol agents to ensure their effectiveness.

- **Chemical spray for non-*Bt*:** Spray Spinosad 45% SC @ 4 mL/10L (200mL/ha) or Chlorantraniliprole 18.5% SC @ 3mL/10L (150mL/ha) or Flubendiamide 39.35% SC @ 2.5 mL/10L (125 mL/ha) or Indoxacarb 14.5% SC @ 10 mL/10L (500 mL/ha).

Crop growth stage: 91–120 DAS

- **Chemical spray for non-*Bt*:** Spray Flubendiamide 39.35 SC @ 3mL/10L (150mL/ha) or Indoxacarb 14.5% SC @ 10 mL/10L (500 mL/ha) or Spinosad 45% SC @ 4 mL/10L (200mL/ha)

3. SPOTTED BOLLWORM

National importance: Spotted bollworm, was initially dominant on *Desi* cotton (*Gossypium arboreum*), but later it also adapted to upland cotton. Before the introduction of *Bt* cotton, spotted bollworm was considered a major pest during 1971–2005 and caused severe economic losses in cotton-growing regions. However, after *Bt* cotton adoption, its status declined to a minor pest in most cotton growing regions of the country.

Species diversity: The spotted bollworm complex in cotton mainly comprises two closely related species, Spotted bollworm (*Earias vittella*) and the spiny bollworm (*Earias insulana*) (Lepidoptera : Noctuidae). In India, *E. vittella* predominates mainly in South and Central India, while *E. insulana* is the dominant species in North Indian cotton ecosystems.

Economic impact: Before *Bt* cotton cultivation, bollworm infestations including spotted bollworm caused yield losses up to 40–50% due to destruction of fruiting bodies and deterioration in fibre quality. Damage results in boll shedding, incomplete fibre development and contamination with larval frass. After adoption of *Bt* cotton, population levels largely remained below economic threshold in most cotton-growing regions of India. However, occasional appearance has been associated with ecological shifts and altered pest-predator dynamics. Reduced efficacy of insecticides has also been observed in some *G. arboreum* cotton-growing regions due to continuous exposure to different chemical groups. The coexistence of both species in major cotton-growing belts of India contributes significantly to their economic importance in cotton production systems.

Nature of damage: Young larvae initially bore into terminal shoots of pre-squaring plants, causing drying and withering of shoots. If the growing point is damaged, the main stem may collapse. Later, larvae attack squares, flowers and bolls by boring internally. Feeding holes are observed on squares and bolls, often accompanied by larval excreta. Flared squares, shedding of squares, premature dropping and improper opening of bolls are characteristic symptoms. Larvae do not remain confined to a single boll and may move from one fruiting body to another, resulting in disproportionate damage. Damaged bolls are also prone to secondary bacterial and fungal infections.

Bud damage

Shoot damage

Younger green boll damage

Mature green boll damage

Seasonal pest incidence: Incidence begins as early as three weeks after crop emergence. Initial infestation occurs on terminal shoots during the vegetative stage, where larvae bore into tender shoots causing drying and withering of growing points. As the crop advances towards reproductive stages, larvae shift to squares, flowers and developing bolls. Beyond 20 weeks after crop emergence, infestation by *Earias* species continues on floral parts and bolls, often resulting in flared squares, premature boll dropping and poor boll opening. Warm and humid weather conditions favour rapid multiplication of the pest, with temperatures between 25°C and 34°C being highly congenial for population build-up and outbreak development. After *Bt* cotton adoption, the pest largely remained below economic thresholds. In recent years, sporadic resurgence has occasionally been observed in *G. arboreum* cotton in North India due to ecological shifts and altered pest-predator dynamics associated with reduced use of broad-spectrum insecticides.

Mark of identification:

Eggs: Eggs are measure about 0.54–0.78 in length, deposited singly on the softest, haired parts of the cotton plant, preferentially on young terminal squares, flower bracts, tender leaf veins, and newly formed green bolls. They are spherical, sculptured, and prominently crown-shaped with distinct vertical ridges radiating from the top. When

freshly laid, they are a light sky-blue or greenish-blue hue, making them blend in with host tissue. They darken slightly to a purplish or brownish shade just before hatching.

Larva: Larval body is mottled with a striking patchwork of creamy-white, dark brown, and orange spots/tubercles running down its dorsum. The full grown larva measures roughly 15 to 18 mm in length. It possesses a stouter, more spindle-shaped body compared to other bollworms, lacks the prominent microspines found on *Earias insulana*, and features a characteristic longitudinal greenish-grey or brownish body segment background.

Pupa : *Earias vittella* pupa measure about 8–9 mm in length, pupation takes place primarily on the plant itself or among fallen plant debris on the soil surface. The pupa is enclosed in a tough, closely woven silken cocoon that mimics an inverted boat shape or a wedge. The internal pupa is obtect, initially a light brown that darkens to a rich chocolate or reddish-brown hue over time.

Adult : The adult moth is relatively small about 9–10 mm, with a wingspan measuring about 20 to 25 mm. The forewings provide an absolute species-specific identification marker. They are pale creamy-white to buff-yellow, marked by a distinct, prominent longitudinal green band or wedge running straight through the center from the base to the outer margin. The hindwings are uniformly semi-transparent, silvery-white with faintly darkened, smoky margins. Adult moths are nocturnal.

Life cycle : Within 2–3 days of mating, the female moth begins oviposition. The female selects tender, hairy, macro-rich zones of the cotton plant, predominantly young terminal

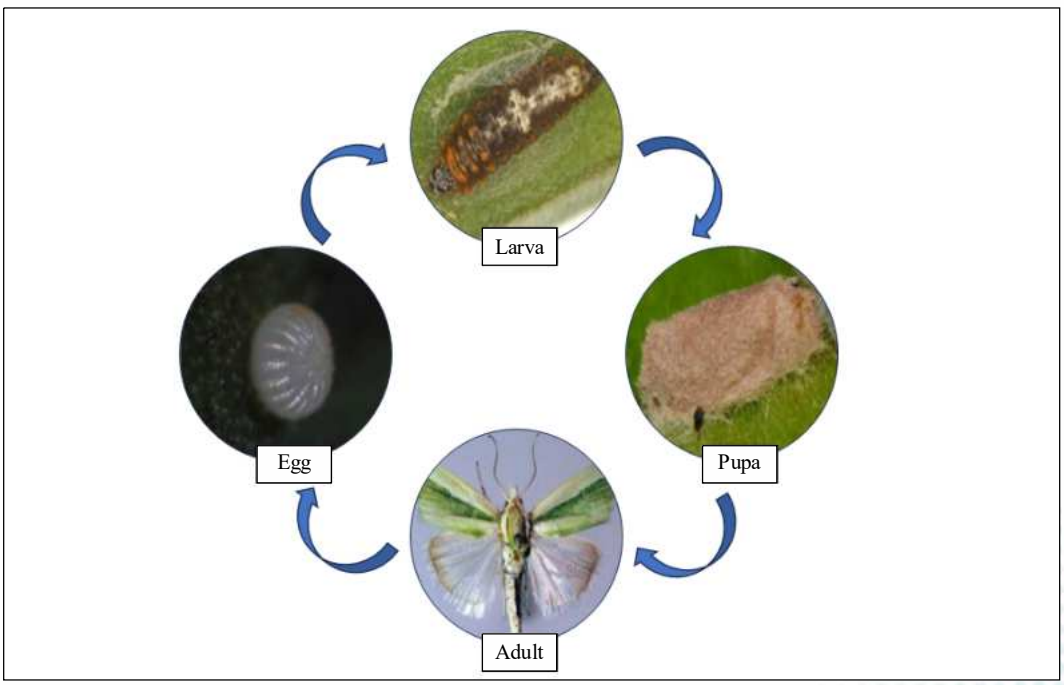


Fig 3. Life cycle of *E. vittela*

shoots, leaf veins, petioles, flower bracts, and the rind of young green bolls. Eggs are laid singly during the night, a single female moth can deposit 158–191 eggs. After 3–5 days of incubation, the larvae hatch out, passes through 5 distinct instars, spanning a total of 11–16 days. Once the larva completes its 5th instar and measures roughly 15–18 mm, it ceases feeding and prepares for pupation. The pupal transformation takes 6–8 days before the adult emerges. The adult moth emerges from the pupa, usually during the early hours of the night. Adult males live for about 4–9 days, while females live longer, between 8 and 12 days. Under optimal tropical agro-climatic conditions, the entire life cycle is completed in 27–43 days. The pest completes multiple overlapping generations within a single cotton season (Rajveer et al., 2016) (Fig 3 & 4).

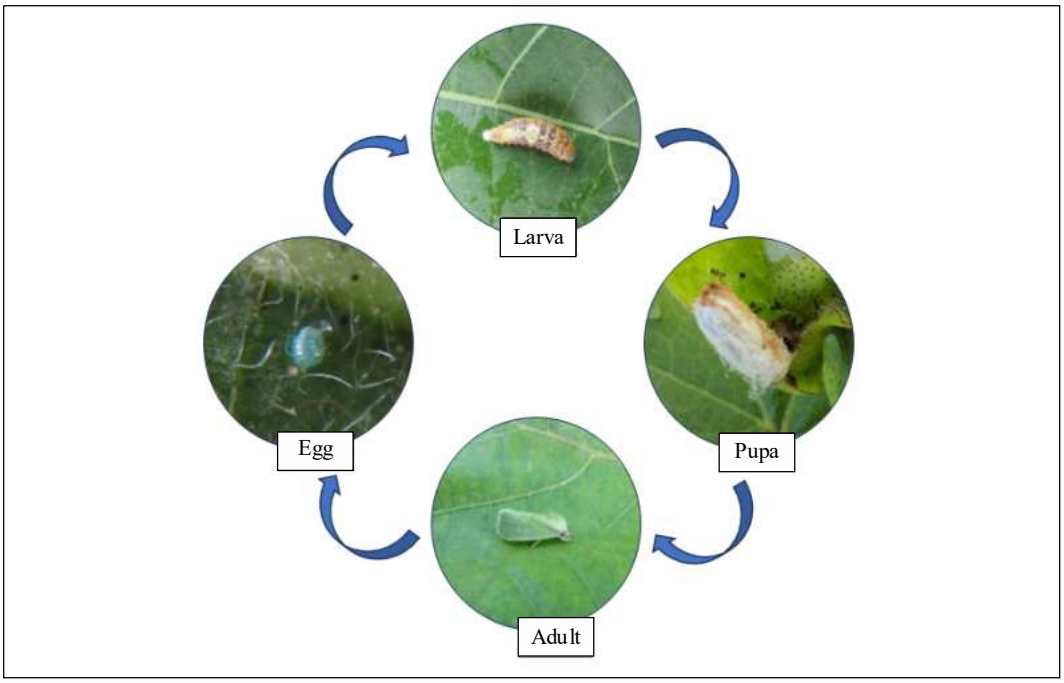


Fig 4. Life cycle of *E. insulana*

Pest surveillance:

i) **Pheromone trap monitoring:** Install pheromone traps @ 5 traps per ha, spaced approximately 50 m apart. Lure should be replaced as per validity. Trapped moths should be removed daily.

ii) **Field scouting:** Monitoring of *Earias* spp. should be carried out through regular field scouting. Field observations at 3–5 days intervals are recommended to assess egg and larval populations on terminal leaves, fruiting bodies, and shed plant material for estimating economic threshold.

Economic threshold: The ET for *Earias* spp. is 20% plants with flared squares or one larva per plant, or 5–10% damaged fruiting bodies.

Management strategy:

Crop growth stage: 0–60 DAS

- **Pruning damaged shoots:** Regularly scout fields for drooping or withered terminal shoots. Clip these damaged shoots slightly below the larval entry hole and destroy them to kill the hidden larvae before they mature.
- **Pheromone traps:** Install species-specific pheromone traps for *Earias vittella* and *Earias insulana* 30 days after sowing. Maintain a density of 2 traps per acre to track the initial influx of adult moths.

Crop growth stage: 61–90 DAS

- **Mechanical control:** Manually collect fallen squares, buds, and aborted reproductive structures from the ground and destroy them to disrupt the pupation cycle in the soil.
- **Biological control:** Begin field releases of the egg parasitoid *Trichogramma chilonis* @ 60,000 /acre at weekly intervals.
- **Chemical control:** For non-*Bt*/*Desi* (*G. arboreum*) cotton, on crossing ET, spray Spinosad 45%SC @ 4 mL/10L (200 mL/ha) or Chlorantraniliprole 18.5%SC @ 3mL/10L (150 mL/ha) or Flubendiamide 39.35% SC @ 2.5 mL/10L (125 mL/ha) or Indoxacarb 14.5%SC @ 10 mL/10L (500mL/ha).
- **Crop growth stage: 91–120 DAS**
- **Chemical control:** For non-*Bt*/*Desi* (*G. arboreum*) cotton, on crossing ET, spray Flubendiamide 39.35 SC @ 3mL/10L (150 mL/ha) or Indoxacarb 14.5%SC @ 10 mL/10L (500 mL/ha) or Spinosad 45% SC @ 4 mL/10L (200 mL/ha)

II. Sucking pests

1. COTTON JASSID / LEAFHOPPER

National importance: The Cotton jassid / Leafhopper, *Amrasca biguttula biguttula* (Ishida), (Hemiptera : Cicadellidae), is widely recognized as one of the most economically devastating sucking pests of cotton in India. While the historic introduction of *Bt* cotton successfully suppressed lepidopteran bollworms initially, it catalyzed a massive ecological shift in Indian agroecosystems. Free from competition and unaffected by *Bt* proteins, sucking pests, spearheaded by the cotton jassid have ascended to the status of primary, yield-limiting biotic stressors across all three major cotton-growing zones of India.

Economic impact: The pest occurs in all the three cotton growing zones of India reducing cotton yield up to 30%.

Nature of damage: Both nymphs and adults typically found nestled between the veins of the leaves on the ventral surface. They suck the cell sap primarily from the underside of leaves, feeding results in distinct downward leaf curling of the leaf margins, yellowing at the edges of the leaves (Nagrare et al., 2025). The symptoms vary depending on the intensity of infestation. The insect also injects toxin into the leaf, resulting in 'hopperburn' symptoms. In advanced stages, the margins may turn brick red or brown.

Yellowing of leaf edges

Downward curling of infested leaves

Leaf bronzing

Cotton jassid affected field

Period of occurrence: Cotton jassid populations persist throughout the cropping season, their transition to economic pest status exhibits distinct regional variations across India's cotton-growing zones. In the North zone, populations peak and attain pest status early, typically during June–July, driven by early-season sowing. Conversely, in the Central and South zones, peak infestations shift to July–August, aligning with the vegetative and early reproductive phases of the crop. The population buildup of this pest is highly sensitive to macro-climatic factors. Extended periods of hot and humid weather, characterized by intermittent rainfall (>80% relative humidity) and low ambient sunlight (cloudy conditions), create an ideal microclimate within the crop canopy. These specific agro-ecological conditions significantly accelerate nymphal survival, shorten generation time, and trigger rapid population explosions.

Mark of identification:

Eggs : Egg measure 0.7–1.0 mm long, creamy white, elongate and inserted within leaf tissues; incubation period 4–11 days.

Nymph : Wingless, pale green to yellowish-green, passing through five instars and increasing from approximately 0.7 mm in the first instar to about 2.3 mm in the fifth instar.

Adult : Slender, wedge-shaped, green insect measuring about 2.1–2.7 mm in length, with a pair of black spots on the head and near the tip of the forewings.

Life cycle:.The life cycle of jassid, consists of egg, four nymphal instars and adult stages. The duration of first, second, third and fourth instars are 2.58 ± 0.57, 2.14 ± 0.81, 2.03 ± 0.63 and 1.84 ± 0.80 days, respectively. The total nymphal period ranged from 5–16 days with an average duration of 8.59 days. Adult longevity varied from 4–25 days with a mean of 13.37 ± 5.17 days. The total life cycle is 15–34 days in males (mean 21.38 ± 5.39 days) and 17–37 days in females (mean 23.19 ± 4.86 days) (Nagrare et al., 2012). (Fig 5)

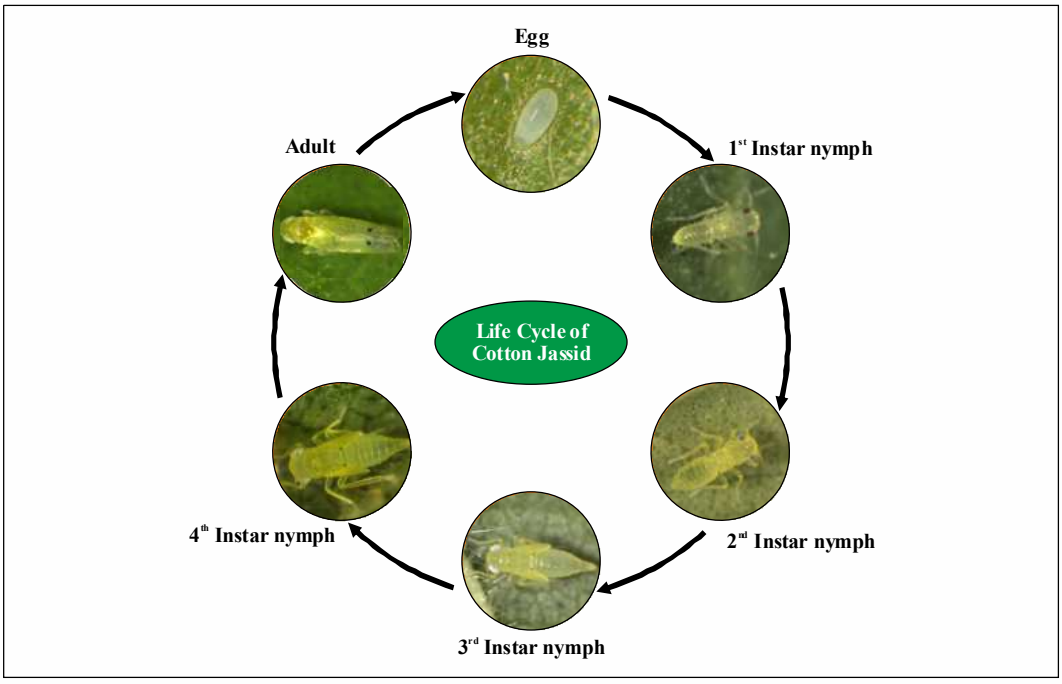


Fig 5. Life cycle of Cotton Jassid

Pest surveillance:

i) **Yellow sticky trap-based monitoring:** Cotton jassid is attracted to yellow colour, it is advised to install yellow sticky traps @ 8 per acre and replace it after a week time.

ii) **Field scouting:** It is necessary to conduct field surveys every 3–5 days to determine whether the ET has been crossed. For cotton jassid, the ET assessment can be done based on the infestation grade or the actual number of insects. The insect count should be taken randomly from 20 plants per acre, checking 3 leaves per plant (one each from the top, middle, and bottom).

Similarly visual observation can be recorded based on grades given in management section.

Economic threshold: Average 2 nymphs per leaf and or ⩾ 5 plants out of 20 randomly observed plants (25% plants infested) showing damage grade II/ III/ IV.

Management strategy:

Crop growth stage: 0–60 DAS

- **Select resistant varieties:** Select resistant varieties / hybrids recommended for the zone
- **Seed treatment:** To protect seedlings for the first 45 days without early foliar spraying, seed treatment is advocated. Commercial seeds are coated with systemics insecticides like Imidacloprid 70 WS or Thiamethoxam 30 FS.
- **Optimize nitrogen application:** Avoid excessive applications of nitrogenous fertilizers. High nitrogen creates succulent, lush foliage that drastically increases nymphal survival and accelerates population build-up. Balance nutrition by applying nitrogen in recommended splits.
- **Field sanitation:** Keep fields and margins free of key alternative weed hosts (e.g., *Abutilon indicum*, *Solanum* spp.) that serve as pest reservoirs during season and the off-season.
- **Yellow sticky traps:** Install yellow sticky traps at a density of 8 traps per acre. Position the traps 30 cm above the crop canopy level to monitor first arrivals and mass-trap adult cotton jassid.
- **Conserve natural enemies:** Avoid early-season broad-spectrum sprays to preserve native populations of green lacewings (*Chrysoperla*), ladybird beetles (Coccinellids), and predatory spiders, which actively consume jassid nymphs.
- **Botanical sprays:** Between 50-60 DAS, spray NSKE 5% + Azadirachtin 0.15 EC @ 5 mL /L or NSKE/neem oil-based formulation 5 mL /L (300 or 1500 ppm) + 1.0 mL surfactant) (Initial 1–2 sprays). (NSKE 25L + Azadirachtin 0.15 EC 2.5L +0.5 L surfactant per ha). Use 150–200 L of water / acre or 375–500 L/ ha for dilution of the insecticides. Repeat the spray after 10–15 days.

Crop growth stage: 61–90 DAS

- **Chemical sprays :** On crossing ET, spray Flonicamid 50%WG @ 4 g/10L (200 g/ha) or Dinotefuran 20% SG @ 3 g/10L (150 g/ha) or Imidacloprid 17.8% SL @ 3 mL/10L (150 mL/ha) or Tolfenpyrad 15%EC @ 20 mL/10L (1000 mL/ha) or Fenpyroximate 5% EC @ 15 mL/10L (750 mL/ha).

Crop growth stage: 91–120 DAS

- **Chemical sprays:** On crossing ET, spray Thiamethoxam 25%WG @ 2 g/10L (100g/ha) or Tolfenpyrad 15%EC @ 20 mL/10L (1000 mL/ha)

2. WHITEFLY

National importance: The whitefly, *Bemisia tabaci* (Gennadius) (Hemiptera: Aleyrodidae), is a highly polyphagous sucking pest, globally known to infect >900 host plants including several economically important crops. It is one of the most destructive sucking pests of cotton worldwide and is widely distributed in tropical and subtropical regions. In India, although whitefly occurs in all cotton-growing zones, it is particularly important in the North Indian states of Punjab, Haryana, and Rajasthan because of its ability to transmit Cotton Leaf Curl Disease (CLCuD), especially in *G. hirsutum* cotton.

Species diversity : *Bemisia tabaci* is the only whitefly species infesting cotton in India and is recognized as a species complex comprising at least 46 genetic groups or cryptic species and so far, 13 groups has been recorded from India. These groups differ in fecundity, host range, insecticide resistance, virus-vectoring ability, and symbiotic bacterial composition. The pest possesses high reproductive potential, rapid dispersal ability, extreme polyphagy, and remarkable capacity to develop insecticide resistance. Globally, *B. tabaci* transmits more than 400 phytopathogenic viruses belonging to genera such as *Begomovirus, Crinivirus, Ipomovirus, Carlavirus, Torradovirus, Polerovirus,* and *Cytorhabdovirus*. In India, Asia II 1 is the predominant genetic group associated with cotton, particularly in CLCuD-prone regions of North India, while Asia I, Asia II 5, Asia II 7, Asia II 8, Asia II 13, and MEAM1/B biotype have also been reported.

Outbreaks: Major outbreaks have been reported during 1929, 1987, 1996, 2015, and 2022, with the 2015 outbreak causing severe reductions in cotton production, productivity, and cultivated area. The 1987 outbreak was associated with the introduction of synthetic pyrethroids, destruction of natural enemies, hormoligosis effects, hot dry weather, and cultivation of susceptible *G. hirsutum* varieties. The 1996 outbreak coincided with severe Cotton Leaf Curl Virus epidemic conditions, delayed sowing, intense heat, and high humidity, resulting in populations reaching 60–140 adults per three leaves in some fields. The 2015 outbreak resulted from favourable climatic conditions, delayed sowing, susceptible hybrids, alternate hosts, excessive nitrogen fertilization, indiscriminate insecticide use, and resistance development. The 2022 outbreak was associated with prolonged sowing windows, susceptible hybrids, imbalance in fertilizer application, abundance of alternate hosts such as summer moong, ecological imbalance due to insecticides, and increasing resistance to several insecticide groups.

Economic impact: Whitefly infestations cause severe economic losses globally as well as in India. Cotton yield losses due to whitefly generally range from 15–20%, but under severe infestation losses may exceed 30%. During the devastating 2015 outbreak in North India, yield losses exceeded 65% in Punjab, leading to compensation of approximately ₹644 crore in Punjab and more than ₹967 crore in Haryana. During the 2022 outbreak, losses ranged from 26% to 100% depending on infestation severity. Increased whitefly incidence has been observed since 2012, and the 2022 outbreak represented the second major population surge within a decade.

Nature of damage: Whiteflies cause both direct and indirect damage to cotton plants. Direct damage occurs through sap sucking by nymphs and adults from the underside of leaves, producing chlorotic yellow spots that later merge and cause generalized yellowing, reduced vigour, and curling of leaves. Continuous feeding reduces photosynthetic activity and ultimately lowers yield. Indirect damage occurs through honeydew excretion, which promotes the growth of sooty mold. Leaves become shiny initially and later blackened by fungal growth. During boll opening stages, lint contamination with honeydew and sooty mold severely affects lint quality and seed development. Whitefly is also an efficient vector of CLCuD, which significantly increases economic losses in North Indian cotton-growing region. Severe infestations often result in visible clouds of adult whiteflies emerging from disturbed crop canopies.

Initial symptoms as yellow island

Severe infestation of whitefly

Development of sooty mould

Blackening of lint

Seasonal pest incidence: Whiteflies remain active from seedling emergence until crop maturity. Warm weather, high temperature, and scanty rainfall favour rapid population build-up and aggravate pest severity. During the off-season, whiteflies survive on alternate hosts including malvaceous crops, cucurbits, crucifers, and perennial weed species, which facilitate carryover between cropping seasons. In the North cotton-growing zone, whitefly populations generally attain two seasonal peaks: the first peak mainly affects crop growth and facilitates CLCuD spread, whereas the second peak adversely affects lint quality and seed development during later crop stages.

Mark of identification:

Eggs: Eggs are pear-shaped, oval, or sub-elliptical with a broad base and a pointed apex, extremely minute, averaging about 0.2 mm in length. They attached vertically to the leaf tissue by a minute basal stalk or pedicel inserted into the stoma. Freshly laid eggs are light yellowish-green to creamy white. Prior to hatching eggs turns dark brown or purplish-black at the apex, with distinct red eye spots of the developing nymph visible through the chorion.

Nymphs: The nymphal phase progresses through four distinct stages. While the first instar is mobile, the subsequent instars are completely sessile, flat, scale-like structures clinging to the underside of middle and lower leaves. First instar nymph (crawler),

functional legs and antennae are present. They are oval, greenish-yellow, and moves a short distance before settling to insert its stylet. In second and third instar, legs and antennae regress into vestigial structures. The body becomes a flattened, oval scale, translucent yellowish-green, making them highly camouflaged against the leaf lamina. Fourth instar (Puparium) nymphs are oval, convex, or disc-like scale, measuring roughly 0.7–0.8 mm in length and opaque, pale yellow to deep golden-yellow in colour. Margin is smooth or weakly crenulate without conspicuous waxy fringes.

Adult: Adult whiteflies are small insects with white wings and yellow bodies covered by a waxy powder, measuring about 1–2 mm in length, with females being notably larger than males. The head, thorax, and abdomen are distinctly pale yellow to sulfur-yellow in colour. Two pairs of wings covered with a fine, powdery white wax. *Bemisia tabaci* holds its wings at an angle in a roof-like or tent-like posture over its abdomen. The wings do not meet completely at the top dorsum, leaving a slight gap through which the yellow body is visible from above. Compound eyes are dark brown to dark red. Adults are highly active when disturbed, flitting rapidly in short flights from the underside of the foliage.

Life cycle: Female lay 60–300 elliptical stalked eggs singly predominantly on the underside of upper and middle canopy leaves, often scattered or in loose clusters rather than strict concentric circles.Eggs hatch within 5–7 days during warm weather, while hatching may take more than 30 days during winter. The first instar nymphs, move briefly before settling on the leaf surface and inserting their stylets into phloem tissues. Thereafter, the nymphs remain sessile throughout development. Nymphal development involves three moults and lasts 9–14 days during summer and 17–19 days during winter. The pupal period lasts 2–8 days. Depending on climatic conditions, the life cycle may range from 17–29 days. Whiteflies complete nearly 12 generations annually and reproduce both sexually and parthenogenetically (Malinga & Laing 2024) (Fig 6).

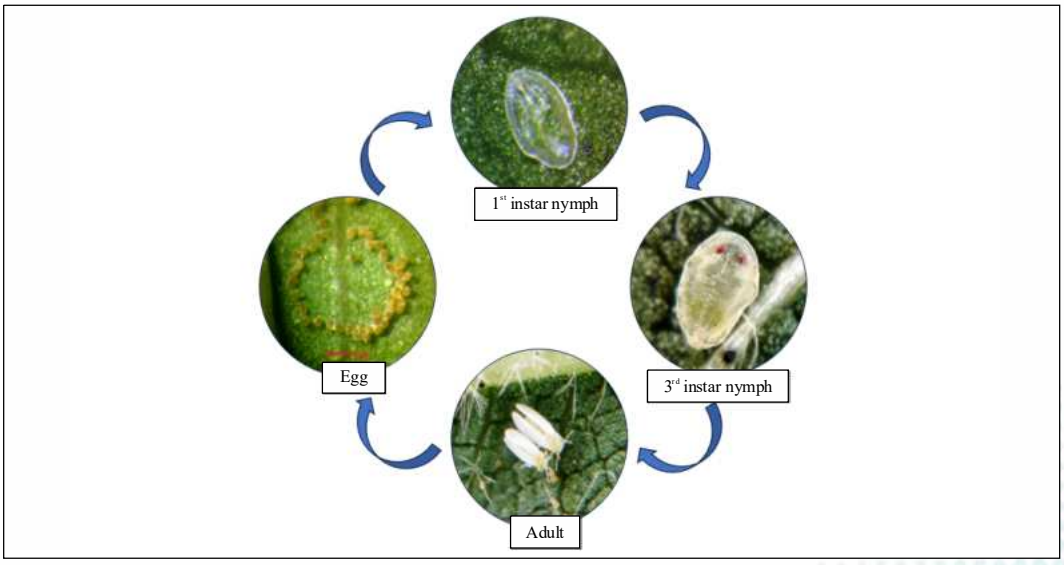


Fig 6. Life cycle of whitefly

Pest surveillance:

i) Yellow sticky trap: *Bemisia tabaci* are highly attracted to the bright yellow/bright amber colour. Yellow sticky traps are one of the most effective, economical, and non-chemical tools for the IPM of cotton whitefly. They serve two critical roles in the field: early-season monitoring/surveillance and mass trapping to reduce adult populations. For monitoring / surveillance, deploy 8 traps per acre uniformly across the field, while for mass trapping deploy 16–20 traps per acre.

ii) Field scouting: Whitefly monitoring is mainly based on observation of adults and honeydew symptoms on the lower surface of leaves. Infested plants exhibit shiny leaves, yellowing, curling, and sooty mold development. During severe infestations, disturbance of plants results in visible clouds of adults flying from the crop canopy. Several surveillance tools including whitefly suction traps and yellow sticky traps have been developed. During surveys at least 20 plants per acre avoiding plants at boundaries and under shade of tree, need to be monitored to assess level of incidence. Observe 3 leaves gently from upper, middle and lower canopy of each plant.

Economic threshold: The economic threshold for cotton whitefly is 6 adults per leaf or more than 50% plants with honeydew.

Management strategy:

Pre-sowing and cultural practices

- **Genotype selection:** Cultivate only high-yielding, whitefly-tolerant, and CLCuD-resistant cotton hybrids or varieties approved by ICAR-CICR, State Agricultural Universities (SAUs), or the Department of Agriculture.
- **Timely sowing windows:** Complete sowing on time to ensure the crop outgrows early pest vulnerabilities. Complete sowing of *Desi* cotton varieties by April 30. *Desi* varieties are immune to CLCuD and naturally tolerant to whitefly. Complete sowing of upland cotton (*G.hirsutum*) hybrids/varieties by May 15.
- **Off-season sanitation:** Keep fields, bunds, irrigation channels, canal banks, and fallow lands free of weeds. Destroy all volunteer or ratoon cotton plants which act as early pest reservoirs.
- **Alternate host monitoring:** Scout for early whitefly populations on surrounding alternative hosts like winter vegetables, ornamentals, and plantation crops before cotton sowing begins.
- **Barrier crops:** Plant two dense rows of sorghum, pearl-millet, or maize as a border crop around cotton fields. Introduce ecological diversity by interplanting *Desi* cotton and other non-host crops to break pest cycles.

Crop growth stage: 0–60 DAS

- **Maintain optimum stand:** Ensure recommended plant populations to avoid overly dense, humid microclimates that favor whitefly breeding.
- **Judicious nitrogen application:** Strictly avoid excessive urea application during early vegetative phase. Excess nitrogen produces soft, succulent tissue that accelerates whitefly population build-up.
- **Initial botanical defenses:** Initiate preventive biological sprays starting at 45 DAS.

Apply two sprays of neem-based formulations at a 15-days interval to suppress early nymph development.

- **Avoid chemical spray:** Do not apply any synthetic pyrethroids or organophosphates. Early use of these broad-spectrum chemistry groups indiscriminately kills natural predators, causing severe whitefly resurgence.
- **Install yellow sticky traps:** Install yellow sticky traps @ 8 per acre during July to August for monitoring and @ 20 per acre for management.

Crop growth stage: 61–90 DAS

- **Mass trapping:** Install yellow sticky traps at a density of 20 traps per acre across the fields to monitor first arrivals and mass-trap migrating adult whiteflies.
- If monitoring indicates whitefly nymph buildup reaches ET, target the immature stages using Insect Growth Regulators (IGRs) or lipid biosynthesis inhibitors.
- **Targeted nymphal population control:** Spray Pyriproxyfen 10%EC @ 20mL/10L (1000 mL) /ha or Buprofezin 25%SC @ 20 mL/10L (1000 mL/ha) or Spiromesifen 22.9% SC @ 12 mL/10L (600 mL/ha).
- **Targeted adult population control:** Spray Diafenthiuron 50%WP @ 12 g/10L (600 g/ha) or Afidopyropen 50g/L @ 20mL/10L (1000 mL/ha) or Dinotefuran 20%SG @ 3g/10L (150g/ha) or Flonicamid 50%WG @4g/10L (200 g/ha) or Clothianidin 50% WDG 1 mL/10L (50ml/ha) or Pyrifluquinazon 20% WG @ 10 mL/10L (500 mL/ha). Direct sprays to hit the undersides of the leaves where whiteflies live and feed.

Crop growth stage: 91–120 DAS

- **Restrict broad-spectrum chemistry:** Continue to avoid all synthetic pyrethroids, organophosphates, and unapproved chemical tank-mixtures during this window to preserve native predatory lacewings, beetles, and spiders.

  North India

- **For whitefly nymph control:** Spray Pyriproxyfen 10%EC@ 20mL/10L (1000 mL /ha) or Buprofezin 25%SC @ 20mL/10L (1000 mL/ha) or Spiromesifen 22.9% SC @ 12mL/10L (600 mL/ha).
- **For whitefly adult control:** Spray Diafenthiuron 50% WP @ 12 g/10L (600 g/ha) or Afidopyropen 50 g/L@ 20 mL/10L (1000 mL/ha) or Dinotefuran 20% SG @ 3 g/10L (150 g/ha) or Flonicamid 50% WG @ 4 g/10L (200 g/ha) or Clothianidin 50% WDG @ 1 mL/10L (50 mL/ha).

  Central and South zones

- Spray Dinotefuran 20 SG @ 3 g/10L (150g/ha) or Spiromesifen 22.9% EC @12 mL/10L (600 mL/ha) or Pyriproxyfen 10EC @ 20 mL/L (1000 mL) or Diafenthiuron 50% WP @ 12 g/10L (600 g/ha) or Profenofos 50 EC @ 30 mL/10L (1500 mL/ha) or Pyrifluquinazon 20% WG @ 10 mL/10L (500 mL/ha).

3. APHID

National importance: Cotton aphid, *Aphis gossypii* Glover (Hemiptera: Aphididae) is one of the most important sucking pests of cotton across tropical and subtropical regions. In

India, it occurs in almost all cotton-growing states. The pest is prevalent in both irrigated and rainfed cotton ecosystems and survives throughout the year on alternate cultivated and wild host plants.

Economic impact: Cotton aphid is highly polyphagous and has been reported on more than 600 plant species belonging to several families. The wide host range enables continuous survival and multiplication of aphids throughout the year. The pest can cause 25–35.6% avoidable yield losses if action is not taken at right stage. In the late season, honeydew secretion on open cotton bolls, the fiber becomes sticky and develops black sooty mold. Farmers can lose 15–20% of their market price due to stained, sticky lint quality.

Nature of damage: Both nymphs and adults suck sap from tender plant parts, reducing plant vigor and productivity. Severe infestation causes leaf curling and yellowing, stunted growth, delayed crop development, and the shedding of squares and young bolls. Additionally, aphids excrete large quantities of honeydew, which promotes the growth of sooty mold, thereby hindering photosynthesis and degrading lint quality. Continuous sap extraction weakens plants and reduces its growth. Under favorable environmental conditions, aphid populations multiply rapidly and can cause substantial economic losses, particularly during early crop growth stages and in rainfed cotton systems.

Curling and crinkling of infested leaves

Aphid infested shoot

Aphid on underside of leaf

Blackening and contamination of lint

Seasonal pest incidence: The seasonal fluctuation of *Aphis gossypii* is strictly dictated by

weather conditions. Seed treatments provide protection up to 45 days. Depending on the region, a minor initial peak can be seen in between 45–60 days. The highest aphid densities can occur after mid October in Central and South India. The temperatures between 22 °C and 27 °C have been reported as favourable range for its development, survival and reproduction (Nagrare et al., 2021). High morning humidity (>90%) followed by moderate evening humidity (60–70%) accelerates aphid reproduction. Heavy, rain washes aphids off leaves, drastically crashing field populations overnight. Conversely, intermittent light drizzles coupled with cloudy weather create a microclimate that sets off sudden, explosive population flares. Prolonged dry spells followed by intermittent rains often favour aphid outbreaks.

Mark of identification:

Eggs: In warmer regions or tropical climates *A. gossypii* rarely lays eggs, it reproduces almost exclusively through parthenogenesis.

Nymph: Nymphs are yellowish to dark green in colour and possesses two horn-like projections, called as "cornicles" on the posterior side of the body. Nymphs progress through four distinct immature instars before reaching adulthood. Nymphs dimensions are 1st Instar: 0.44–0.56 mm length, 0.23–0.38 mm width, 2nd Instar: 0.55–0.70 mm length × 0.35–0.44 mm width, 3rd Instar: 0.70–0.88 mm length × 0.42–0.52 mm width, 4th Instar: 0.90–1.15 mm length × 0.50–0.60 mm width. 1st instar nymphs possess exactly 4 antennal segments while 2nd through 4th possesses 5 antennal segments.

Adult: Adult body lengths range from 1–2 mm, plump, pear-shaped, and broad. Bodu colour mottled dark green to bluish-black in cool weather; small and pale yellow to white in hot weather. Eyes are distinctly red or dark reddish-brown. Antennae are shorter than the body, with dark tips and a pale middle section.

Life cycle : The nymphal period of cotton aphid ranges from 4.5–6.0 days, while adults survive for about 8–10 days. Under favourable temperature conditions of 25–30°C, the pest completes its life cycle within 7–9 days. Each female produces an average of 7–13 nymphs during its lifetime. Owing to its short life cycle and rapid reproductive potential, the pest is capable of completing more than 30 generations annually (Saha et al., 2016; Nagrare et al., 2021).

Yellowish coloured aphid adult with cornicles on posterior abdomen

Aphid colony on lower leaf surface

Pest surveillance:

i) **Field scouting:** Observe 20 plants per acre in 'Z' or 'X' pattern, avoid the absolute borders of the field for main count, as edge effects can artificially inflate aphid numbers. Inspect field at 3-5 days interval.

Economic threshold: 10% plants showing symptoms cupping / crumpling of few leaves on the upper portion of plant.

Management strategy:

Crop growth stage: 0–60 DAS

- **Seed treatment:** Commercial seed available in the market are pre-treated with neonicotinoids (Imidacloprid/Thiamethoxam), protect the seedlings against sucking pests for the first 35–40 days. If seed are not pre-treated, it is advised to treat the seed with either of insecticide before sowing.
- **Chemical restriction:** Do not apply any chemical or neonicotinoid sprays during this initial 60 days window. This period allows populations of beneficial insects to build up. Early chemical use will kill these predators and stimulate an aphid outbreak.
- **Fertilizer management:** Use optimum dose of urea preferably in split doses. Use neem-coated urea for slow nutrient release. High nitrogen use makes the plant highly attractive to aphids.
- **Preventive botanical spray:** NSKE or neem oil suggested for pink bollworm will help to suppress early aphid numbers without harming friendly insects.

Crop growth stage: 61–90 DAS

- **Economic threshold based intervention:** Only apply a recommended chemical insecticide if the aphid population crosses the ET of 10% infestation.

Crop growth stage: 91–120 DAS

- **Chemical control:** If aphids exceed the 10% ET, use chemicals such as Cyantraniliprole 10.26% OD @ 900 g/ha, Diafenthiuron 50% WP @ 600 g/ha, Dimpropyridaz 120 g/L SL @ 700 mL/ha, Dinotefuran 20% SG @ 180 g/ha, Dinotefuran 70% WG @ 87 g/ha.
- **Avoid pyrethroid:** Avoid pyrethroid insecticides (like cypermethrin, lambda-cyhalothrin, fenvalerate). Using them before 120 DAS heavily aggravates sucking pest numbers and will result in severe crop damage.

Crop growth stage: >120 DAS

- **Late-stage management:** No need to take up separate spray, insecticides sprayed against pink bollworm will take care of aphids.

4. THRIPS

National importance: As like cotton jassid, the introduction of *Bt* cotton altered the pest landscape in India, elevating thrips to a position of critical national importance. Long considered as a minor or localized early-season nuisance, thrips have emerged as a primary, persistent sucking pest complex capable of derailing crop establishment and severely

depressing fiber productivity across all three major cotton-growing zones. Beyond direct feeding injuries, thrips carry immense national importance as highly efficient vectors for devastating viral pathogens. They are the primary vectors of Tospoviruses, such as the Tobacco Streak Virus (TSV) disease in India.

Species diversity: Thrips species *Thrips tabaci, Thrips palmi, Scirtothrips dorsalis, Thrips hawaiiensis, Thrips florum, Frankliniella schultzei* and the invasive *Thrips parvispinus*. Among these, *T. tabaci* and *T. palmi* are dominant species in all the three zones while *S. dorsalis* in South zone (Amutha and Rachana, 2023, Nagrare et al., 2024).

Economic impact: Thrips have emerged as major sucking pests of cotton, limiting crop productivity through direct feeding and transmitting viral pathogens. Thrips can reduce lint yield by 30–50% in cotton (Cook et al., 2011; Kaur, 2014).

Nature of damage: Characterized by leaf wrinkling and upward curling of the leaf margins (compare this to Jassids, which cause downward curling). The laceration results in distinct silvery or brownish necrotic spots and patches on the underside of the leaves. In high infestation levels, the plant's terminal growth is hindered, leading to overall stunted development and significant yield reduction. Due to TSV, necrotic patches on leaves, square drying, and systemic stunting associated with virus transmission can lead to localized crop failures, making thrips management a strict phytosanitary priority.

Upward curling

Silvery patches

Brown patches

Infested plant

Period of occurrence : Thrips thrive in hot and dry climates. Their population usually peaks during June–August in North India while July–August in Central and South India. Prolonged dry spells during these months often lead to severe outbreaks. In recent years, thrips have emerged as one of the most important sucking pests of cotton in North India. Their incidence and severity have increased substantially since 2021, with several locations reporting populations above the Economic Thresholds. Field surveys conducted by ICAR-CICR indicated a marked rise in thrips populations during the 2023 cotton season, with the percentage of surveyed locations exceeding ET increasing from 6.12% in 2021 and 8.24% in 2022 to 37.59% in 2023 (Kumar et al., 2023). The prolonged dry weather, high temperatures, low rainfall, indiscriminate use of insecticides, and changes in cropping patterns have been considered major factors contributing to these outbreaks. The increasing frequency of thrips outbreaks highlights the need for regular surveillance and integrated pest management strategies in North Indian cotton ecosystems.

Mark of identification:

Eggs: Eggs are kidney-shaped to bean-shaped, smooth, translucent white to pale yellow, and are inserted singly within the leaf tissue, making them difficult to observe externally. Freshly laid eggs measure approximately 0.20–0.30 mm in length and 0.08–0.12 mm in width. Before hatching, the eggs become slightly yellowish, and the developing embryo may be visible through the chorion.

Nymph: Nymphs are minute, slender, wingless, and yellowish to pale green in color. They pass through two active feeding instars and are highly mobile on leaf surfaces. First-instar nymphs measure approximately 0.3–0.5 mm, while second-instar nymphs reach 0.6–1.0 mm in length. Their microscopic size makes them difficult to detect without a hand lens. The body is elongated, soft-bodied, and tapering towards the abdomen.

Pre-pupa and Pupa: The pre-pupal and pupal stages are non-feeding and relatively inactive. Both stages are pale yellow with developing wing pads. The pre-pupa measures about 0.8–1.0 mm, while the pupa measures 0.9–1.2 mm in length. These stages are commonly found in concealed locations on plants or in soil debris.

Adults: Adults are small, slender insects measuring approximately 1.0–1.5 mm in length and 0.2–0.3 mm in width. Their colour varies from pale yellow to light brown or dark brown depending on species and age. A distinguishing characteristic is the presence of narrow fringed wings, with long hair-like setae along the wing margins. Adults are agile, capable of short flights, and readily disperse among cotton plants.

Life cycle: The life cycle of *Thrips tabaci* consists of six stages: egg, first instar larva, second instar larva, pre-pupa, pupa, and adult. About 100 eggs are inserted into leaf tissues and hatch within 4–6 days. The first and second larval instars remain active feeders up to 10 days, respectively. The non-feeding pre-pupal stage lasts for 1–3 days, followed by a pupal stage of 3–4 days. Adults survive for about 10–30 days depending upon host plant and environmental conditions (Malinga and Laing, 2024) (Fig 7).

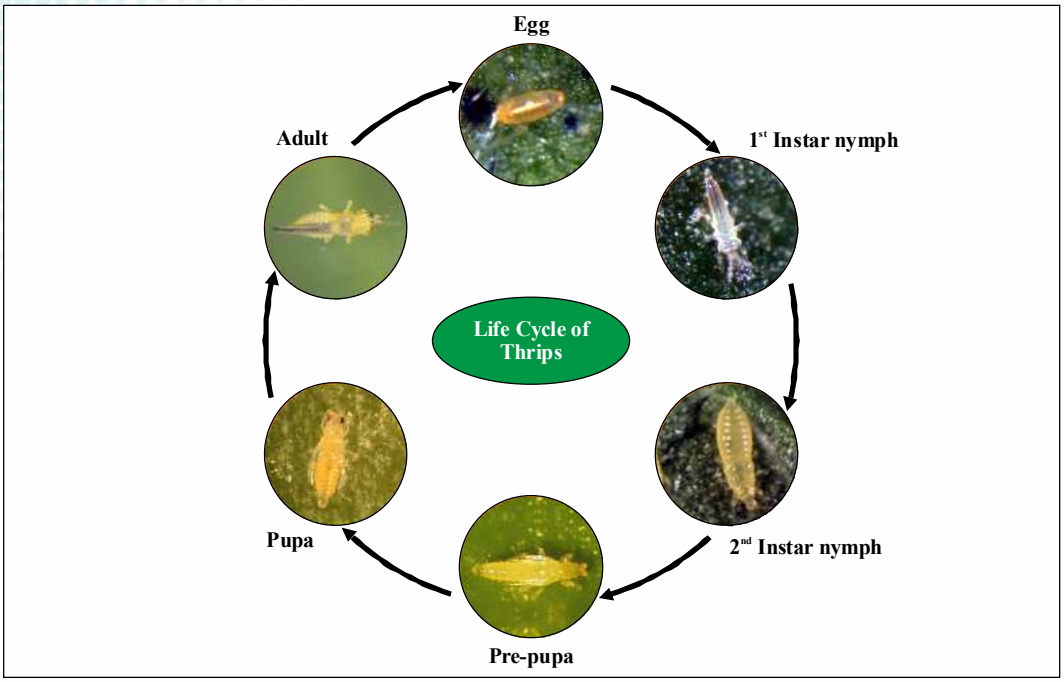


Fig 7. Life cycle of thrips

Pest surveillance:

i) **Field scouting:** Similar to Cotton jassid it is necessary to conduct field surveys every 3–5 days to determine whether the ET has been crossed. The ET assessment can be done based on the infestation grades or the actual number of insects. The insect count should be taken randomly from 20 plants per acre, checking 3 leaves per plant (one each from the top, middle, and bottom).

Visual observation can be recorded based on grades given in the management section.

Economic threshold: 10 thrips per leaf and /or ⩾ 5 plants out of 20 plants randomly observed showing silvery patches on underside of leaves above mid canopy (25% plants infested).

Management strategy:

Crop growth stage: 0–60 DAS

- **Seed treatments:** To protect seedlings for the first 45 days seed treatment is advocated. Commercial seed are coated with systemic insecticides like Imidacloprid 70 WS@ 5–10 g/kg seeds or Thiamethoxam 30 FS @ 10 mL/kg seeds.
- **Field sanitation:** Field and field bunds should be free from weeds and Parthenium weed should be eradicated in and around the fields.
- **Scout early for TSV risks :** Closely monitor the crop during its initial growth stages for any signs of thrips infestation. Early detection is critical for assessing and

checking the risk of Tobacco Streak Virus (TSV) transmission.

- **Install blue sticky:** Install blue sticky traps at a density of 8 traps per acre. Thrips are highly attracted to the blue color; these traps will help to catch the first arrivals and accurately tracking population trends.
- **Optimum use of nitrogenous fertilizers:** High, uncalibrated basal doses of nitrogenous fertilizers produce soft, highly succulent seedling tissue that triggers exponential thrips population explosions. Use balanced and split applications of nitrogenous fertilizers

Crop growth stage: 61–90 DAS

- **Scout for TSV risks:** Closely monitor the crop during its initial growth stages for any signs of thrips infestation. Detection is critical to assess and check the risk of Tobacco Streak Virus (TSV) transmission.
- **Chemical sprays:** On crossing ET, spray Thiamethoxam 25%WG @ 2 g/10L (100 g/ha) or Spinetoram 11.7% SC @ 8.4 mL/10L (420 mL/ha) Or Profenofos 50%EC @ 30mL/10L (1500ml/ha) or Tolfenpyrad 15% EC @ 1000 mL/ha or Buprofezin 25%SC @ 20 mL/10L (1000 mL/ha) or Dinotefuran 20% SG @ 150 g/ha or Diafenthiuron 50% WP @ 600 g/ha for the management of thrips infestation to check the transmission of TSV.

Crop growth stage: 91–120 DAS

- **Chemical sprays:** Spray Thiamethoxam 25%WG @ 2 g/10L (100 g/ha) Or Spinetoram 1.7% SC @ 8.4 mL/10L (420 mL/ha)

5. COTTON MEALYBUG

National importance: The cotton mealybug, *Phenacoccus solenopsis* Tinsley (Hemiptera: Pseudococcidae), holds national importance as an exotic, invasive, and highly destructive pest within the cotton agroecosystem. *P. solenopsis* presents a significant threat to agriculture and horticulture in many tropical and subtropical countries, posing a severe threat to cotton production, especially in Asia; the climate of many of these cotton-producing regions is highly favorable for its colonization and establishment (Wang et al., 2010). Although cotton mealybug infestation peaked during 2007 and 2008 (Nagrare et al., 2009), it was reduced to minor pest status from 2011 onwards. Currently pest seen in trace.

Economic impact: Severe infestation can cause seed cotton yield reduction up to 50% (Nagrare et al., 2009)

Nature of damage: Both nymphs and adults suck sap from all parts of the plant. Plants infested with mealybugs during the vegetative stage exhibit stem distortion, twisting, bunchiness or bushiness of the affected portions, and severely stunted growth. While feeding, they inject toxic saliva into the plant tissue, inducing severe chlorosis, premature senescence, defoliation, and complete drying up of the plant in extreme cases. Furthermore, the bugs excrete large quantities of sticky honeydew. This sugary coating serves as a substrate for black sooty mold fungi, which block photosynthesis and drastically degrade the quality of the lint and fiber.

P. solenopsis colony on underside of leaf

P. solenopsis infested young plant

P. solenopsis infested stem

P. solenopsis infested boll

Seasonal pest incidence: As young cotton seedlings establish in the field, early mealybug populations begin migrating from surrounding weeds or border vegetation. At this vegetative stage, the initial infestation appears in small, scattered patches or clusters, often restricted to a few plants near field edges. With the onset of the reproductive stage, the population begins to multiply rapidly. The expanding plant canopy provides ample feeding sites and protection. Crawlers actively disperse upward to colonize tender apical shoots, leaf petioles, and squares. The pest population reaches its peak during the boll development and bursting stages. Huge, cottony-white colonies wrap around developing bolls and branches. Warm temperatures coupled with drying weather create ideal conditions for multiplication.

Mark of identification:

Eggs: *P. solenopsis* is ovoviviparous or viviparous, the eggs develop fully inside the female, and female primarily deposits highly active, live young (crawlers). Eggs are measuring about 0.30–0.40 mm length and 0.34–0.37 mm width. The individual eggs are minute, oval-shaped, and possess a pale yellow to translucent amber coloration. They are enclosed within a prominent, white, loosely woven, cottony waxy mesh known

as an ovisac. The ovisac is typically constructed beneath or at the posterior end of the adult female body, anchoring the colony to the cotton stem, leaf, or boll.

Nymph: First instar nymphs also called as 'Crawlers' are tiny (roughly 0.3–0.5 mm long), elongated-oval, and completely devoid of the thick white waxy coating adults. They have a distinct yellowish to light-brown body, functional legs, and active antennae, allowing them to crawl rapidly across the plant canopy in search of fresh feeding sites. These are the primary dispersal stage. Second (0.75–1.15 mm) and third instars nymphs (1.40–2.05mm) settle and begin feeding, their bodies widen and become covered with a thin, powdery layer of white wax.

Male pre-pupa and pupa: Male pre-pupa is measured about 1.10–1.40 in length while pupa is 1.25–1.55 mm in length.

Adult: The adult female is small, measuring approximately 2.5–5.0 mm in length, and is covered by a white, powdery mealy wax. Distinct dark, dorso-submedian bare spots on the body surface align to form a prominent pair of dark longitudinal lines down the dorsum. This small body size, protective waxy coating, and the ability to feed on all plant parts collectively enable *P. solenopsis* to colonize and spread rapidly over extensive areas. In contrast, the adult male looks entirely different, resembling a tiny, delicate, two-winged gnat or fly. It has an elongated, greyish-flesh-colored body measuring about 0.95–1.20 mm and possesses a single clear pair of wings for flight. Adult males are short-lived.

Life cycle: *P. solenopsis* is known for its high reproductive capacity, producing 128–812 offspring per female with a 95% female-biased progeny on cotton, completing several generations a year. The developmental period for females was recorded as 13-16 days, compared to 18–19 days for males. The reproductive period lasted 22–38 days. Furthermore, adult females lived for 27–42 days, whereas males survived for only 1–2 days (Vennila et al., 2010, Nagrare et al., 2018) (Fig 8).

Pest surveillance: As like other sucking pests, farmer should visit weekly interval. Initial infestations almost always appear near field edges, irrigation channels, or bunds where alternate weed hosts like *Parthenium hysterophorus* or *Abutilon theophrasti* reside. The presence of active ant trails on cotton stalks is a primary bio-indicator. Ants attracts mealybugs for their sugary honeydew and actively defend them from natural predators, often moving crawlers to fresh plant tissue. Early-season crawlers look for shelter from heavy rains and direct sunlight, settling on the lower stems, leaf axils, and underside of leaves.

Economic threshold: 5–10% of the sampled plants in a field score at Grade 2 or more (small, localized clusters of mealybugs established on a single branch or apical shoot tip) or above.

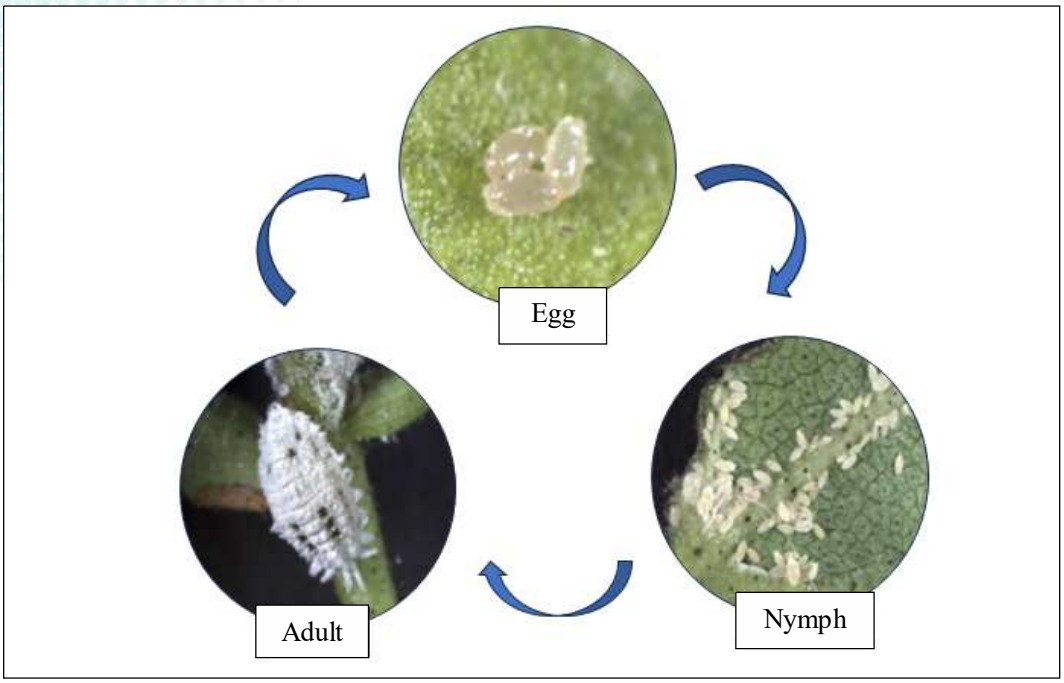


Fig 8. Life cycle of *P. solenopsis*

Management strategy:

Crop growth stage: 0–60 DAS

- **Sanitation of field borders:** Remove and destroy weeds along field bunds, irrigation channels, and nearby roadsides. Prioritize removing key alternate hosts like *P. hysterophorus* and *A. theophrasti*.
- **Regular scouting:** Initiate weekly field scouting, paying special attention to border rows and ant activity.
- **Ant management:** Mealybug distribution is heavily aided by symbiotic ants. If active ant nests are spotted along bunds or at plant bases, apply localized drenching or dusting around the field perimeter to disrupt their trailing network.
- **Mechanical eradication:** If isolated, scattered plants show early Grade 1 or Grade 2 infestations, carefully uproot and destroy them, or prune the infested twigs and bury them away from the field to eradicate early patches.
- **Biopesticides:** Spray a botanical insecticide like neem formulation as a prophylactic measure to deter early crawler settlement.

Crop growth stage: 61–90 DAS

- **Conservation of natural enemies:** This is the peak arrival time for the highly effective endoparasitoid *Aenasius arizonensis*. Avoid applying broad-spectrum synthetic

pyrethroids or organophosphates, as they wipe out these beneficial insects and trigger severe mealybug resurgence.

- **Spot applications:** Do not spray the entire field if the infestation is localized. Restrict chemical applications strictly to infected "hot spots" and a 2-meter buffer zone around them.
- **Targeted insecticides:** If mealybug infested plants cross the 5–10% ET, spray, insect growth regulators (IGRs) or soft chemistry, such as Buprofezin 25% SC @ 1000 mL/ha or Flonicamid 50% WG @ 200 g/ha.
- **Adjuvant addition:** Always mix a quality surfactant, sticker, or washing powder (0.5–1.0 g/L) into the spray tank. This breaks down the water-repellent, white waxy coating on the mealybug's body, ensuring the insecticide directly contacts the insect skin.

Crop growth stage: 91–120 DAS

- **Intense surveillance:** Evaluate the intensity of the infestation using the standard 0–4 grading scale. Look closely for the accumulation of sticky honeydew and black sooty mold on middle and lower leaves.
- **Assess parasitism rates:** Check the colonies for "mummies" bloated, hard, metallic-brown mealybug shells. If more than 40–50% of the mealybugs are mummified by *Aenasius arizonensis*, withhold chemical sprays and allow the biological agents to complete control.
- **Chemical spray:** If natural enemy counts are low and the infestation aggressively crosses the ET (>10% plants at Grade 2 or higher), deploy effective chemical such as Profenofos 50% EC @ 1500 mL/ha, Chlorpyrifos 50% EC 800 mL/ha or Chlorpyrifos 20% EC @ 1250 mL/ha.
- **Thorough coverage:** Ensure the spray volume is sufficient to cover thoroughly underside of leaves where mealybugs tightly cluster.

Crop growth stage: >120 DAS

- **Protect lint quality:** Heavy mealybug excretion during boll bursting stains the lint, severely degrading its market value. Maintain spot treatments if late-season flushes appear on remaining green bolls.
- **Phased harvesting:** Ensure timely picking of opened bolls to minimize exposure to falling honeydew and sooty mold.
- **Stalk management and clean cultivation:** Immediately after the final picking, do not leave the cotton stalks standing in the field for grazing or extended periods. Uproot the cotton crop on time.
- **Sanitary field clearance:** Avoid stacking infested cotton stalks on field bunds, as they act as a massive overwintering reservoir. Shred or dispose of the residue properly, and perform deep summer ploughing to expose hidden soil-dwelling nymphs to solar heat before the next season.

6. PAPAYA MEALYBUG

National importance: The emergence of the papaya mealybug (PMB), *Paracoccus marginatus* Williams & Granara de Willink (Hemiptera: Pseudococcidae) as a significant pest of cultivated cotton carries immense national importance. Originally an invasive alien species native to Central America, PMB was first reported in India (Tamil Nadu) in 2008. While it established its notoriety by devastating horticultural crops, its subsequent adaptation and expansion into major cotton tracts across South and Central India have elevated it to a high-priority biosecurity and economic challenge. Since 2011, the pest is in trace.

Economic impact: The economic impact of the PMB on cotton cultivation in India represents a major financial risk for farmers and the textile supply chain. While originally feared as a tropical fruit pest, its adaptation to cotton has made it a highly destructive and costly sucking pest. In severe, unmanaged outbreaks during warm and dry periods, PMB can cause yield losses ranging from 30 –100%.

Nature of damage: Both nymphs and adult females insert mouthparts into vital plant tissues to feed continuously on phloem sap. Continuous extraction of plant sap deprives tissues of moisture and vital nutrients, leading to general plant weakness and a withered appearance. While feeding, PMB injects toxic salivary fluids into the plant tissues. This causes localized phytotoxemia, resulting in severe crinkling, twisting, and distortion of leaves. The terminal growing flushes become heavily congested and malformed. The stems thicken and become brittle, bending into a stunted growth. The PMB clusters heavily around leaf petioles, the bases of squares, and young green bolls. The combined physical stress and salivary toxicity trigger the plant to drop its squares and young bolls prematurely. Bolls that manage to survive the infestation remain abnormally small, dry up prematurely, or fail to open completely, destroying the developing fiber inside. A black saprophytic sooty mold establishes on honeydew secretion, turning the entire plant canopy black that affect photosynthesis.

Colony of papaya mealybug on leaf

Severely infested plant

Sooty mould development on leaves

Sooty mould development on opened boll

Seasonal pest incidence: The pest occurs throughout the season under favourable warm and humid climatic conditions. Population build-up is commonly observed from vegetative to boll opening stage.

Mark of identification:

Eggs: The eggs are tiny, oval, and distinctly greenish-yellow measuring about 0.24–0.42 mm length and 0.13–0.19 mm in breadth, enclosed inside a thick, white, waxy ventral ovisac.

Nymphs: Nymphs are pale yellow, resemble adult females, but are smaller. First instar crawlers are about 0.35–0.45 mm, second instar female 0.61–0.75 mm, second instar male 0.62–0.69 mm, third instar female 0.93–1.32 mm.

Pre-pupa and Pupa: Third instar male (Prepupa)≈ 1.05mm, fourth instar male (Pupa)≈1.20 mm.

Adult: Females are small, soft-bodied, oval, yellowish, wingless, approximately 2.0 to 2.2 mm long covered with white waxy secretions and marginal wax filaments. The body is covered in a powdery white wax. A key field diagnostic feature is that when the waxy coating is rubbed off or when the insect is preserved in alcohol, the body turns a distinct pale yellow. Short, stout waxy filaments line the entire margin, with the tail filaments being slightly longer. Males are slender, winged about approx. 1.0 mm, and short-lived, fragile, elongated insect with a pinkish-to-reddish body. It possesses one pair of clear, functional wings and two long, white, wax-like caudal filaments extending from the abdomen tip. It lacks functional mouthparts and cannot feed.

Life cycle: A single female can deposit between 150 to 650 eggs within this protective ovisac over a 5 to 8 days period. Eggs hatch into mobile crawler nymphs, which disperse and settle on tender plant parts for feeding. The female passes through three 3 stages (egg→nymph→adult) while male passes through 5 stages (egg→ 2 nymphal Instars→prepupa→pupa→adult). Males undergo a pupal-like stage before emergence as winged adults. The life cycle generally lasts 25–35 days, depending on environmental conditions, allowing multiple overlapping generations per year. Adult females live for 18–30 days on cotton, continuously feeding and producing eggs (Afroze et al., 2024).

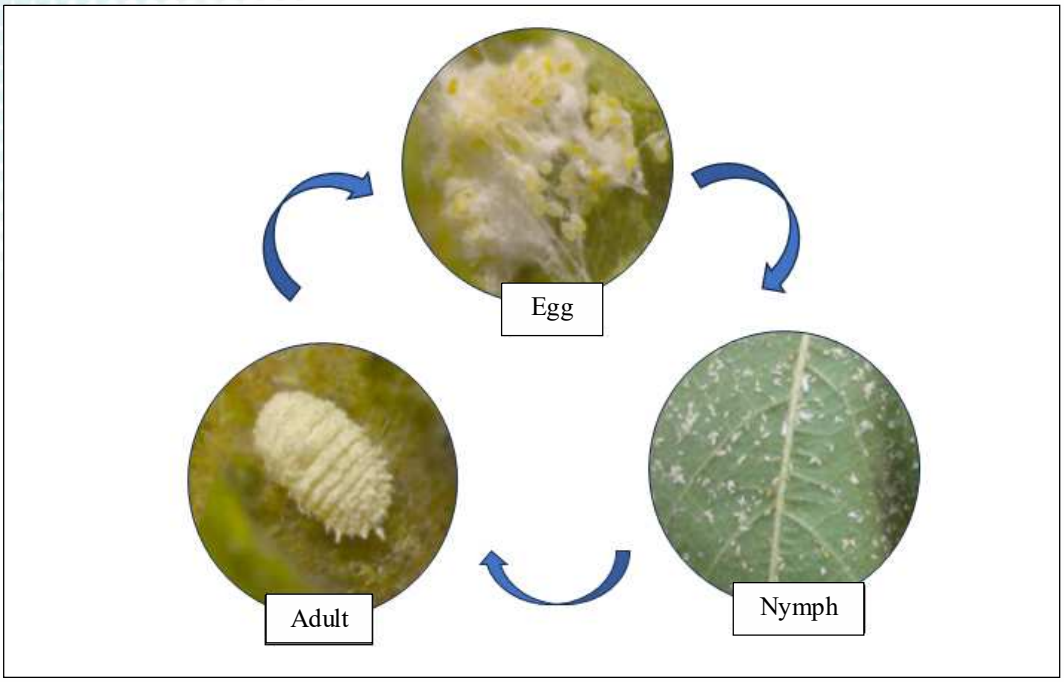


Fig 9. Life cycle of Papaya mealybug

Pest surveillance:

i) **Field scouting:** Regular surveillance should be conducted from the early crop stage onwards, especially on tender shoots, leaf undersides, etc. The presence of white cottony masses, honeydew secretion, ant activity and sooty mold is an important indicator of infestation. Yellowing and curling symptoms on young leaves should also be carefully monitored for early detection.

Economic threshold: 5–10% of plants show visible mealybug infestation or when colonies begin to establish on tender plant parts.

Management strategy:

Crop growth stage: 0–60 DAS

- **Avoid alternate host crops:** Brinjal, bhendi, tomato, tobacco and sunflower.
- **Field sanitation:** Removal and destruction of alternate weed hosts like *A. indicum* and *Solanum nigrum* from the fields and neighbouring areas and maintaining field sanitation.
- **Crop rotation:** Adoption of crop rotation with non-preferred hosts such as sorghum, ragi, maize.
- Removal and destruction of heavily infested plant parts, and control of ants that aid in pest dispersal.

- **Judicious use of nitrogenous fertilizers:** Avoid excessive use of nitrogenous fertilizers, which favour pest multiplication.

Crop growth stage: 61–90 DAS

- Conservation and release of biological control agents such as *Acerophagus papayae, Anagyrus loecki,* and ladybird beetles are highly effective for sustainable management.
- Spray Imidacloprid 17.8% SL @ 150 mL/ha or Buprofezin 25% SC @ 1000 mL/ha or Diafenthiuron 50%WP @ 600 g/ha or Thiacloprid 21.7% SC @ 600 mL/ha or Flonicamid 50% WG @ 180 g/ha or Thiamethoxam 25% WG @ 100 g/ha.

Crop growth stage: 91–120 DAS

- Spray Imidacloprid 17.8% SL @ 150 mL/ha or Buprofezin 25% SC @ 1000 mL/ha or Diafenthiuron 50%WP @ 600 g/ha or Thiacloprid 21.7% SC @ 600 mL/ha or Flonicamid 50% WG @ 180 g/ha or Thiamethoxam 25% WG @ 100 g/ha.

7. MIRIDS

National importance: The mirid bug (Hemiptera: Miridae) represents one of the most prominent examples of pest status elevation in the history of Indian cotton cultivation. Historically classified as a negligible or minor pest, mirid bugs have emerged as a primary, economically devastating sap-sucking pest complex especially in South India. Their importance is intrinsically tied to the structural ecological shifts that occurred following the commercial introduction of *Bt* cotton.

Diversity: Indian cotton mirid bug *Creontiades biseratense* (Distant), Green mirid *Campylomma livida* Reuter, Mirid *Hyalopeplus lineifer* Walker are the three species reported to infest cotton in India. The problem is most acute in the Southern cotton growing zone (Karnataka, Telangana, Andhra Pradesh, and Tamil Nadu), in these states, *C. biseratense* (Distant), is the predominant and highly destructive species. While in Central and North zones species like *C. livida* and *H. lineifer* Walker are seen.

Economic impact: Field assessments indicate that heavy, unmanaged infestations result in direct yield losses ranging from 10–35%.

Nature of damage: Both nymphs and adults feed on the terminal growth, squares, flowers, and bolls of cotton plants using their piercing-sucking mouthparts, causing the excessive shedding of flowers, small squares, and immature bolls. While developing bolls usually do not shed, they can suffer damage to one or more locules, often resulting in a characteristic 'parrot-beak' deformity. Mirids are present throughout the cotton-growing season, with populations peaking between 50–100 days after crop emergence. Furthermore, the punctures left on maturing bolls allow secondary fungal and bacterial pathogens to enter, leading to internal boll rot and severe lint staining both of which degrade lint quality and lower market prices.

Adult mirid

Parrot beak symptoms

Seasonal pest incidence: *Creontiades biseratense* generally makes its first appearance in the field around 70 days after sowing. Populations show, gradual increase from September, culminating in a major peak during October and November. Research indicates that maximum populations over 17–24 bugs per 5 to 10 squares typically occur between the second fortnight of October and the third week of November. The population usually experiences a decline through mid-to-late December (Sahana et al., 2023).

Mark of identification:

- **Eggs :** Eggs are measuring about 1 mm in length, elongated, cigar-shaped, or slightly curved. They are initially glistening white, becoming creamy white as embryonic development progresses.
- **Nymph :** Fully grown nymphs are measuring about 4–5 mm in length with pronounced wing pads apple-green to yellowish-green in colour.
- **Adult :** Adults are swift fliers, measuring approximately 6.5–7.5 mm in length, with an elongated, narrow, and somewhat flattened body, characteristically light green to brownish-green or yellowish-brown dorsally, with a pale green venter.

Life cycle: About 15 eggs are laid per female mainly in petiole, incubation period 5–6 days, nymphal period 12–16 days, male life cycle complete in 35–47 days while female cycle complete in 33–46 days (Udikeri et al., 2010).

Pest surveillance : Monitoring to be initiated from the square initiation phase (50–60 DAS) and continue through peak squaring, flowering, and early boll development up to 130–140 DAS. Observe about 20 plants per acre following 'X' or 'Z' pattern. Maintain maximum vigilance from September through November. Scout the fields at weekly intervals. Increase frequency to every 3–4 days if the local weather shows prolonged cloudy days with high relative humidity. Gently look under the bracteoles of the squares. Count and record the total number of nymphs and adults per plant or per 100 squares.

For tall, dense cotton canopies where visual counting in squares becomes difficult, place a clean, white plastic sheet or cloth (3 x 3 feet) directly beneath the middle and upper fruiting branches. Gently bend and shake the branches 3–4 times over the sheet. Count the scurrying nymphs that drop onto the surface immediately before they fly or crawl away.

Economic threshold: 5–10 mirid bugs (nymphs + adults) per 20 plants or more than 5% square/fruiting body damage or shedding accompanied by staining.

Management strategy:

Crop growth stage: 0–60 DAS

- **Cultural practices:** Ensure fields and borders are kept strictly free of alternative weed hosts (e.g., *Parthenium hysterophorus*, *Abutilon indicum*) which harbor early generations.
- **Intercropping and border crops:** Grow border rows of maize, sorghum, or pearl millet to act as physical barriers and pollen hubs for generalist predators. Intercropping with cowpea or green gram encourages early-season buildup of natural enemies.
- **Botanical spray:** Neem based spray recommended for pink bollworm would deters early mirid colonization without harming beneficial insects.

Crop growth stage: 61–90 DAS

- **Intensive scouting:** Initiate weekly scouting.
- **Biological control:** Conserve and encourage natural field predators, especially mirid-eating assassin bugs (*Isyndus heros*), green lacewings (*Chrysoperla zastrowi sillemi*), and predatory pentatomid bugs.

Crop growth stage: 91–120 DAS

- **Canopy management:** Avoid excessive nitrogenous fertilizer, which triggers lush vegetative growth and attracts heavy mirid populations.
- **Chemical intervention:** If the population crosses ET, apply insecticides such as Flonicamid 50 WG @ 200g/ha, Diafenthiuron 50 WP @ 600g /ha, Clothianidin 50 WDG @ 125 g/ha, Thiamethoxam 25 WG @ 100 g/ha. Rotate chemistries to prevent insecticide resistance buildup.
- **Spray technique:** Ensure thorough canopy coverage, directing the spray toward the middle and upper fruiting branches where the bugs reside under bracts.

Crop growth stage: >120 DAS

- **Damage control:** Monitor top bolls for feeding punctures. If late-season secondary peaks emerge in irrigated setups, any of the above insecticides can be repeated.
- **Crop termination:** Avoid extending the crop unnecessarily through late irrigations, which provides a continuous food source for the pest to overwinter.
- **Post-harvest sanitation:** Cleanly remove and destroy crop residues after the final picking. Avoid stacking cotton stalks in field borders, as dry stalks and leftover debris can shelter overwintering adult populations or eggs embedded in residual tissues.

III. Other pests

1. TOBACCO CATERPILLAR

National importance: Tobacco caterpillar, *Spodoptera litura* Fabricius (Lepidoptera: Noctuidae), is an economically significant, highly polyphagous insect pest of national

importance in Indian agriculture. The pest is recognized as a sporadic or secondary pest in cotton ecosystems compared to key pests like *Helicoverpa armigera*. In the post *Bt* era the pest found in sporadic manner across all three cotton-growing zones of India.

Economic impact: The larvae feed on a wide range of plants and has been recorded from over 40 mostly dicotyledonous plant families. Larvae of the pest attack the crop in large numbers and are damaging and gregarious in nature. The destructive capacity of *S. litura* spans across multiple growth stages of the cotton plant, resulting in direct yield losses ranging from 10–30% depending on the severity of the outbreak and agro-climatic conditions.

Nature of damage: The freshly hatched larvae feed gregariously on the lower leaf surface, scraping the chlorophyll and leaving skeletonized appearance. The grown-up larvae are solitary, feed voraciously and cause heavy defoliation by skeletonizing the leaves. Late instars (3^{rd}–5^{th}) larvae disperse individually. Being voracious feeders, they completely consume the leaf laminae, causing extensive defoliation. Beyond defoliation, larvae bore into squares, flowers, and developing bolls. They consume the internal contents and cause extensive shedding of fruiting forms, directly impairing lint yield and quality.

Solitary larva

Skeletonized leaves

Larva feeding on cotton boll

Infested cotton bolls

Seasonal pest incidence : The pest appears in the initial phase of crop growth. Damage is localized, restricted to gregarious neonate feeding that creates skeletonized leaves. At boll

development stage, mature larvae bore into young, developing bolls.

Mark of identification :

Eggs: Individual egg is measuring about 0.4–0.6 mm in length, spherical, somewhat flattened, and pearly white to pale yellowish-green when freshly laid. Eggs are deposited in egg masses containing 100–300 eggs, typically glued to the underside of lower cotton leaves. The entire egg mass covered with a protective layer of buff-colored/golden-brown scales and hairs.

Larva: The 1st and 2nd instars larvae are tiny, measuring 1–4 mm. They are translucent green with a distinct dark, shiny head capsule. They are easily identified by their gregarious behavior. Third and 6th instar larvae grow up to 33–43 mm, the body color turns stout and ranges from velvety blackish-green to dark brown or dull gray. A pair of prominent, black, semi-circular or crescent-shaped spots located dorsally on the mesothorax and the 8th abdominal segment. A bright, conspicuous longitudinal yellow or orange-yellow stripe running down each side of the body.

Pupa: Pupa is obtect, measuring 14–23 mm in length, smooth, glossy, and transitions from a fresh reddish-brown to a deep mahogany-brown as adult emergence approaches, found 3 –5 cm deep into soil.

Adult: Adult moth measured about 15–20 mm in length, have a wingspan of 32–38 mm, forewings are gray to reddish-brown, with a complex pattern of creamy streaks and paler lines along the veins. The hindwings are semi-translucent, pearly white with a bluish sheen, bordered by a narrow, dark-brown band along the outer margin and prominent dark veins. When at rest, the wings are folded roof-like over the abdomen.

Life cycle: A single female can lay up to 703 eggs, which are deposited in distinct masses containing 100–300 eggs each. The larvae hatch in 2–3 days and feed for 19–24 days. Pupation takes place in the soil, and adults emerge after about 7–12 days, completes life cycle in approximately 32–40 days. Under favorable agro-climatic conditions, the insect completes 6–8 generations annually (Ashwini et al., 2016) (Fig 10).

Pest surveillance:

i) **Pheromone trap monitoring :** Pheromone traps act as an early-warning system by monitoring the density and flight activity of male adult moths before they lay eggs in the field. Install pheromone traps @ 5 traps per ha across the representative cotton block and change lure as per validity. Always maintain traps on wooden stakes so that the trap canopy rests 1 foot above the crop canopy. Adjust the height periodically as the cotton crop grows. Need weekly observations.

ii) **Field scouting :** Visual scouting can be conducted weekly starting from the vegetative phase (August onward in Central and Southern India) to determine if pest populations have breached the ET. Walk the field in 'X' or 'Z' pattern shape, select 20 plants at random per acre leaving border rows, carefully inspect the lower surface of mid- and lower-

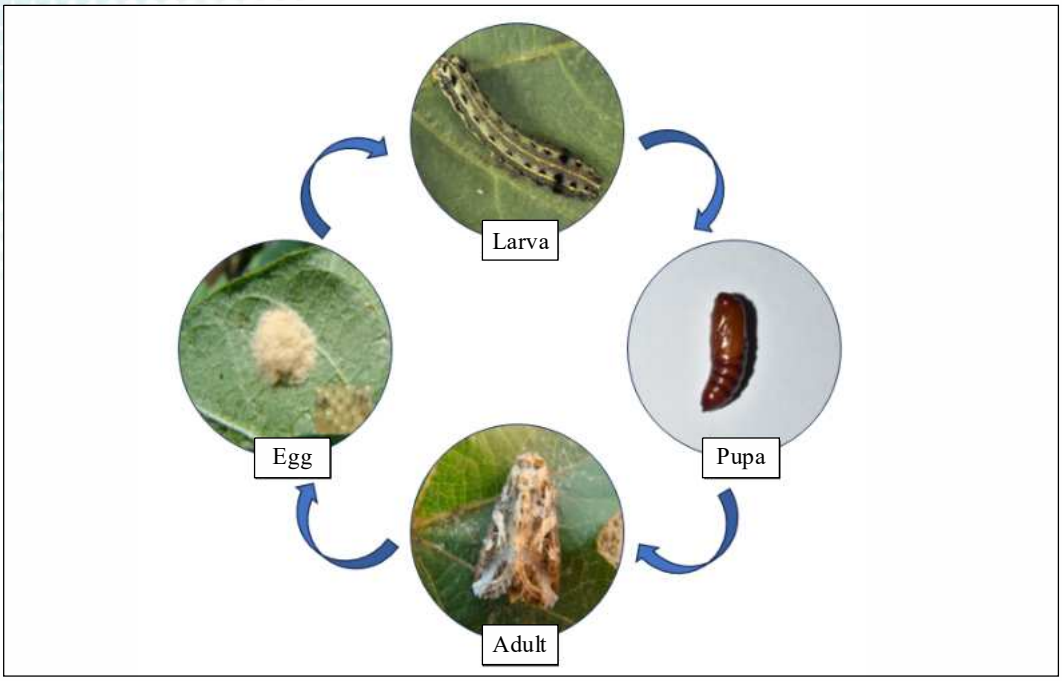


Fig 10. Life cycle of Tobacco Caterpillar

canopy leaves for the characteristic buff-colored, hairy egg masses, scout for skeletonized leaves where early-instar larvae have grazed on the chlorophyll layer in groups. During the reproductive phase, closely check squares, flowers, and young bolls for entry holes, frass, and hidden tunneling by late-instar larvae.

Economic threshold : ⩾2 Egg mass or cluster of gregarious larvae or ⩾10 infested plants (50%) having ⩾5 solitary full-grown larvae/plant.

Management strategy:

Crop growth stage: 0–60 DAS

- **Cultural and preventative measures:** Manually collect and destroy egg masses and gregarious larval clusters.
- **Mechanical monitoring**: Install pheromone traps @ 5 traps/ha at 30 DAS to monitor adult moth activity.

Crop growth stage: 61–90 DAS

- **Scouting and mechanical control :** Intensify visual field scouting for buff-colored egg masses and skeletonized leaves. Collect and destroy egg masses and gregarious larvae found on lower leaf surfaces.
- **Biological and microbial Control :** Spray *Spodoptera litura* Nuclear Polyhedrosis

Virus (SlNPV) @ 250 LE/ha along with 0.1% teepol/jaggery during late evening hours to target 1st to 3rd instar larvae. Encourage natural predators like assassin bugs (*Rhynocoris marginatus*) and green lacewings (*Chrysoperla*) by avoiding broad-spectrum synthetic chemicals.

- **Chemical intervention :** If populations cross ET, use insect growth regulators or green chemistry molecules that disrupt larval moulting such as Novaluron 8.8 % SC @ 1000 mL/ha or Diflubenzuron 25 % WP @ 350 mL/ha or Spinetoram 11.70 % SC 450 mL/ha.

Crop growth stage : 91–120 DAS

- **Chemical intervention:** For severe field infestations on crossing ET, spray Chlorantraniliprole 18.5% SC @ 150 mL/ha, Chlorantraniliprole 47.85 % SC @ 50 mL/ha.

2. TEA MOSQUITO BUG

National importance: The emergence of the Tea Mosquito Bug (TMB), *Helopeltis spp.* within the cotton ecosystems of India marks a critical shift in the country's agricultural landscape. Historically feared as a destructive pest of perennial plantation crops like tea and cashew, its expanding host range to annual field crops like cotton gives it substantial regional importance, especially in south India.

Diversity: Three species of TMB viz., *Helopeltis theivora* (Waterhouse), *H. antonii* (Signoret) and *H. bradyi* (Waterhouse) have been reported on cotton in India, among them *H. theivora* is the dominant cotton invader.

Economic impact: Under standard, non-epidemic field conditions where TMB populations cross the initial action threshold, the avoidable yield loss is typically observed around 30–35%. In highly favorable weather conditions or heavily neglected fields, TMB damage escalates sharply, resulting in yield losses reaching 50% or more.

Nature of damage: Both nymphs and adults possess piercing-sucking mouthparts. TMB injects phytotoxic salivary enzymes that causes localized necrosis, leading to extensive premature shedding of squares and young bolls. Surviving bolls develop deep, sunken scabs that stunt opening. This damages internal locks, stains the lint, and severely downgrades the market value of the cotton fiber.

Seasonal pest incidence: Population build-up is generally higher during cool weather with moderate temperatures and high humidity. Incidence is more during flushing and flowering periods.

Mark of identification:

Eggs: Eggs are measuring about 1mm in length, elongated, embedded within plant tissues, with two fine filamentous processes protruding outside the plant surface.

Nymph: The nymphal body color transitions sequentially through development, freshly hatched first instars are pale orange-red, shifting to yellowish-green during the second

Tea mosquito bug adult

Tea mosquito bug damage on fresh leaves

Tea mosquito bug damage showing bunchy appearance

Tea mosquito bug damage showing suncken spots on boll

and third instars, green in the fourth instar, and finally darkening to a deep green by the fifth instar. Adult *H. theivora* exhibited pronounced sexual dimorphism in both body size and pronotal coloration. Females are significantly larger than males, displaying a distinct yellowish-brown pronotum, whereas the male pronotum are typically dark brown (Yao et al., 2025).

Adult: Tea mosquito bugs are slender, delicate, reddish-brown insects with long legs and antennae. The body is elongated with a characteristic needle-like feeding beak. Adults possess transparent wings and a distinct, elongated thoracic spine or scutellar process projecting upward from the back. TMB adults are slender, elongated (about 6–8 mm), and dark brown to blackish. Females are noticeably larger than males and feature a characteristic yellowish-to-greenish patch or abdominal band. *Helopeltis antonii* distinct from *H. theivora* by its coloration; it features a more pronounced reddish-brown pronotum, a black head, and a contrasting black-and-white abdomen. While *H. bradyi* are very similar in appearance to *H. antonii*, but can be taxonomically distinguished by a characteristic white band located at the base of its hind legs.

Life cycle: A single healthy female of *H. theivora* can lay up to 177 eggs over her reproductive life under optimal field conditions. Eggs are completely inserted inside tender

cotton tissues (midribs, leaf petioles, and soft stems). The only visible sign from the outside is a pair of tiny, silvery, hair-like chorionic respiratory filaments projecting from the plant tissue. The eggs hatch in 6–8 days into orange-yellow, wingless nymphs. They pass through 5 distinct instars over 8–14 days, rapidly transitioning into destructive sap-sucking adults. Adult males live for approximately 9–14 days, while egg-laying females survive longer, typically around 12–18 days. Life cycle completed in 25–39 days (Jakkoksung et al., 2023, Paul et al., 2025).

Pest surveillance: Regular field surveillance should be conducted during vegetative, flowering, and fruiting stages. Tender shoots and young bolls should be examined for fresh feeding punctures, necrotic lesions, and drying symptoms. The presence of active nymphs and adults on tender plant parts during early morning or evening hours is an important indicator of infestation. Sticky traps may also help in monitoring adult activity.

Economic threshold: Management measures should be initiated when 2–3 bugs per plant are observed or 10–15% of tender shoots show fresh feeding damage symptoms.

Management strategy:

Crop growth stage: 0–60 DAS

- **Field sanitation:** Maintain field sanitation by regularly pruning and destroying infested terminal shoots and dried plant parts to eliminate localized pest reservoirs.
- **Canopy management:** Avoid overcrowding and maintain adequate aeration within the crop canopy through timely pruning. This reduces the shaded, humid microclimate that favors *Helopeltis* multiplication.
- **Balanced nutrition:** Apply fertilizers based on soil test recommendations. Avoid excessive nitrogenous fertilization, which triggers succulent vegetative growth and accelerates pest buildup.
- **Conservation of natural enemies:** Encourage and protect native bio-control agents such as predatory spiders, reduviid bugs, coccinellids, and egg parasitoids by minimizing the indiscriminate use of broad-spectrum synthetic insecticides.
- **Botanical interventions:** Spray of neem-based formulations recommended for pink bollworm during the early vegetative stage help to suppress initial pest colonization.

Crop growth stage: 61–90 DAS

- **Chemical control:** Spray insecticides like Clothianidin 50% WDG @ 50 g/ha or Thiamethoxam 25% WG @ 100 g/ha.

3. COTTON STEM WEEVIL

National importance: Cotton stem weevil, *Pempherulus affinis* (Faust) (Coleoptera: Curculionidae) has gained importance following the widespread cultivation of *Bt* cotton, changes in agronomic practices, and continuous cotton cultivation, which favoured its establishment and spread. The pest is of regional importance restricted to South India especially in Tamil Nadu.

Economic impact: Infestation by the cotton stem weevil results in severe economic losses

due to seedling mortality and reduced boll production. Severe infestation may cause up to 65.8% plant mortality, 72% reduction in boll formation, and nearly 78.9% reduction in seed cotton yield. In highly susceptible summer-irrigated crops, mortality levels may exceed 60–90%, especially during the early crop growth stages.

Nature of damage: The damaging stage of the pest is the grub, which bores into the stem and feeds internally on vascular tissues. Feeding results in gall formation near the collar region, disruption of nutrient transport, wilting, and stunted growth. Characteristic swelling and tunnelling symptoms are commonly observed in affected plants.

Stem weevil affected plant

Swollen stem (Gall) near root zone

Glaire on the cotton stem

Tunnelling of grub inside the stem

Seasonal pest incidence: Cotton stem weevil thrives in humid and warm environments. The pest occurs predominantly during the early crop growth stage, particularly from 8–45 days after sowing. Young seedlings are highly susceptible to infestation. The incidence is generally higher in irrigated, ratoon, and off-season cotton crops, with peak infestation commonly observed during the post-monsoon period.

Mark of identification:

Eggs: Eggs are extremely small measuring approximately 0.40 mm in length and 0.29 mm in breadth, oval, and smooth-shelled, milky-white when freshly laid, turning pale yellow just before hatching, laid singly inside small cavities excavated by the female in the bark of the cotton stem, right at the collar region.

Grub: The grubs are "C"shaped measuring about 5–6 mm long and 1.2–1.5 mm wide, creamy white to pale yellow, legless, and remain concealed within the stem throughout their development, surrounded by frass.

Pupa: Measuring about 3.5–4.2 mm long and 1.5–1.8 mm wide, light yellow or creamy at first, gradually darkening to a brownish hue as it nears adult emergence, found securely inside a small, oval pupal chamber prepared by the mature grub right within the burrowed stem gallery.

Adult: Very small weevil, measuring roughly 3–3.5 mm in length and 1.2–1.4 mm breadth, dark brown or grayish-black body with a highly characteristic mottled appearance due to patches of whitish/grey pubescence on the elytra. Possesses a prominent, curved snout, and a distinctly humped or convex thorax.

Life cycle: The female lays about 50–121 eggs in tender stem tissues during her lifetime. The egg stage lasts for 6–10 days, followed by a larval period of 35–60 days. The grubs tunnel inside the stem and complete development within the plant. Pupation occurs inside a pupal chamber formed within the feeding tunnel, and the pupal stage lasts for 9–12 days. Adult longevity ranges from 12 to 50 days, depending on environmental conditions.

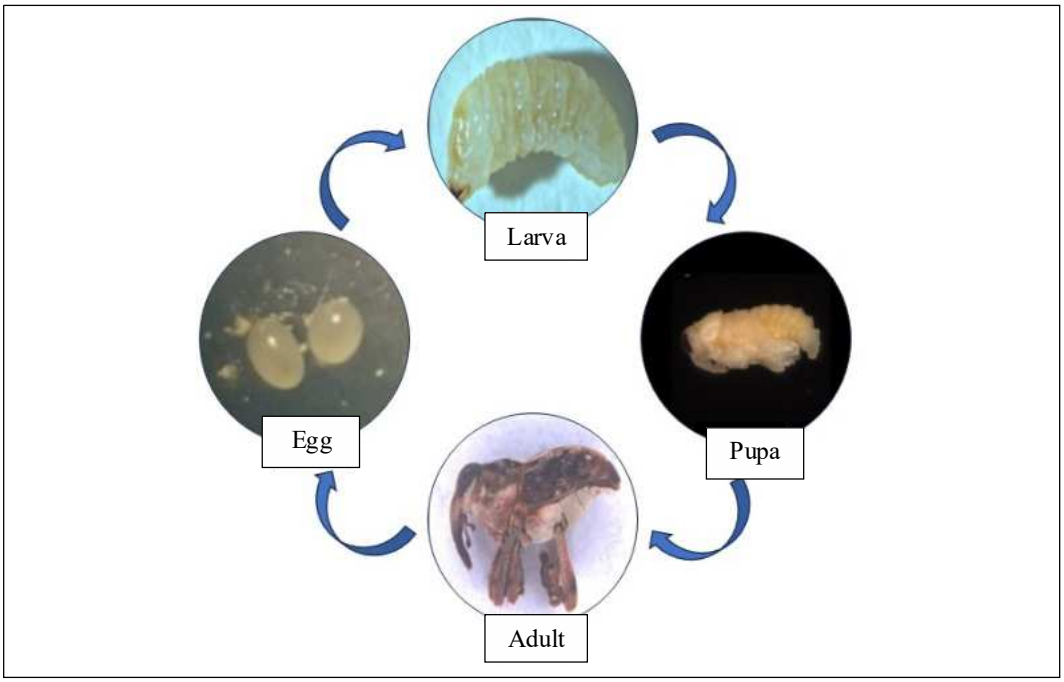


Fig 11. Life cycle of stem weevil

Pest surveillance:

i) **Field scouting:** Regular field scouting should be undertaken during the seedling stage, especially from 8–45 days after sowing. Monitoring involves observing stem swelling, gall formation, wilting symptoms, and the percentage of infested plants. Recording the

number of galls per plant and surveying ratoon or off-season cotton fields helps assess pest incidence and carryover populations.

Economic threshold: At present, no standard ET has been established for cotton stem weevil under Indian conditions. However, management interventions are recommended immediately upon noticing initial symptoms such as stem galls, wilting, or early seedling infestation (10 % plant infestation).

Management strategy:

Crop growth stage: 0–60 DAS

- **Field sanitation and weed management:** Promptly uproot and destroy infested plants. Clear alternative weed hosts such as *Abutilon* and *Sida* spp. from field borders to eliminate pest refuges.
- **Crop rotation:** Rotate cotton with non-host crops like sorghum, maize, or ragi to effectively break the life cycle.
- **Sowing window:** Ensure timely sowing within the recommended window. Avoid continuous or off-season cotton cultivation to prevent pest carryover across seasons.
- **Intercropping:** Intercrop cotton with companion crops like maize, cluster bean, green gram, or field bean to reduce pest pressure and promote natural enemies.
- **Soil amendment:** During land preparation, incorporate a basal mixture of Farmyard Manure (FYM) at 10 t/ha combined with Neem Cake at 250 kg/ha to improve soil health and suppress early-stage pest infestations.

Crop growth stage : 61–90 DAS

- **Biological control:** Conserve key natural parasitoids associated with the pest, particularly *Spathius critolaus*, *Euderus pempheriphila*, and *Aplastomorpha calandrae*.
- **Chemical intervention:** For early-stage protection, drench the collar region with Chlorpyrifos 20% EC at 15 and 30 DAS. During peak infestation, as an ad hoc recommendation, apply foliar spray of Chlorantraniliprole 18.5% SC @ 150 mL/ha or Clothianidin 50% WDG @ 50 mL/ha.

4. DUSKY COTTON BUG

National importance: Dusky cotton bug, *Oxycarenus hyalinipennis* Costa (Hemiptera: Lygaeidae), is an important emerging sucking pest of cotton in India. It occurs throughout all cotton-growing zones however, severe infestations have been reported particularly from Punjab, Haryana and Rajasthan during the late boll opening stage in the recent years. The pest is widely distributed across tropical and subtropical regions of Asia, Africa, and parts of the Middle East.

Economic impact: Dusky cotton bug causes both quantitative and qualitative losses. Feeding on seeds reduces seed weight by up to 15% and oil content up to 6% under severe infestations. Seed germination decline drastically, sometimes up to 88%. Lint staining due to

crushing of insects during ginning lowers fibre quality and market price which impacts the commercial grade and export value of cotton. Early season infestations also reduce square retention due to shedding of flower buds.

Nature of damage: Both nymphs and adults feed gregariously on immature and developing seeds inside open bolls. Feeding reduces seed development and maturity, resulting in shrivelled, discoloured and lightweight seeds with poor germination. Severe infestations may reduce seed viability. The insects also stain lint thus affecting quality. During picking and ginning, adults and nymphs get crushed and release body fluids and excreta that produce indelible black, yellowish or pinkish stains on lint, thereby reducing market value. Infested lint often develops unpleasant odour. Heavy infestations during the early crop stage causes cotton squares to change from green to pale yellow followed by shedding.

Dusky cotton bug infestation on flower

Dusky cotton bug infestation on partially opened boll

Congregation of Dusky cotton bug between locules

Congregation of Dusky cotton bug on opened boll

Seasonal pest incidence: The infestation generally begins in brackets of green bolls and available open bolls. Whereas in squares the infestation is visible immediately after squaring (10 weeks after sowing). Dry weather during boll opening favours rapid multiplication. Ideal temperatures for development ranged between 20°C and 36°C, while rapid population buildup occurs during hotter months between 35°C and 40°C when some moisture is

available. Population growth declines during winter months from November to January when temperatures fall below 30°C, resulting in hibernation on alternate host plants. Dry to slightly humid conditions with relative humidity between 24–32% are highly favourable for multiplication, whereas high humidity above 65–80% negatively affects population buildup and increases mortality.

Outbreak: During the pre-*Bt* cotton era, pest incidence remained relatively low because the secondary pests were inadvertently suppressed by the repeated application of broad-spectrum insecticides used against bollworms. However, in the *Bt* cotton era, the reduced use of broad-spectrum insecticides, particularly towards the end of the cropping season, has favored the survival and multiplication of this pest. Consequently, high population perpetuate and infest the crop from the early stages of crop growth, leading to significant damage till maturity. During 2025–26 season outbreak like situation was seen in North India.

Mark of identification:

Eggs: The eggs are cigar-shaped, slender, and white; measuring approximately 0.97 mm in length and 0.29 mm in width, the shell features about 25 distinct longitudinal ribs or corrugations.

Nymph: Newly hatched nymphs are orange-red in colour gradually darken to a deep brown or red with a distinct greenish hue as they mature. By the fifth instar, well-developed wing pads are visible, extending posteriorly to the third abdominal segment. The average body length increases steadily across the five instars, measuring approximately 1.20 mm in the first instar, 1.58 mm in the second, 2.25 mm in the third, 2.86 mm in the fourth, and 3.70 mm in the fifth.

Adult: Adults measure approximately 4–5 mm in length and possess pointed heads, with females typically being slightly larger than males. The male abdomen terminates in a rounded lobe, whereas the female abdomen appears truncated. Dorsally, adults exhibit a dusky brown body, translucent dirty-white wings with distinct black spots on the forewings, prominent bright red compound eyes, and deep red legs.

Life cycle: Eggs are laid singly or in small groups, loosely scattered among seeds in open bolls. Each female lays an average of 151 eggs, which have an incubation period of 5–7 days. The insect passes through five nymphal stages, lasting a combined total of roughly 28–30 days. Mated males and females exhibit median lifespans of 28 and 25 days, respectively (Saveer et al., 2024) (Fig 12).

Pest surveillance : The pest population is generally aggregated around open bolls, especially under hot and dry weather conditions. Monitoring is mainly based on observation of yellowing and shedding of early-season squares and the presence of nymphs and adults on open bolls. Open bolls should be examined regularly during boll-opening stages for aggregation of bugs and lint staining symptoms.

Economic threshold : 10–15 nymphs and adults per plant.

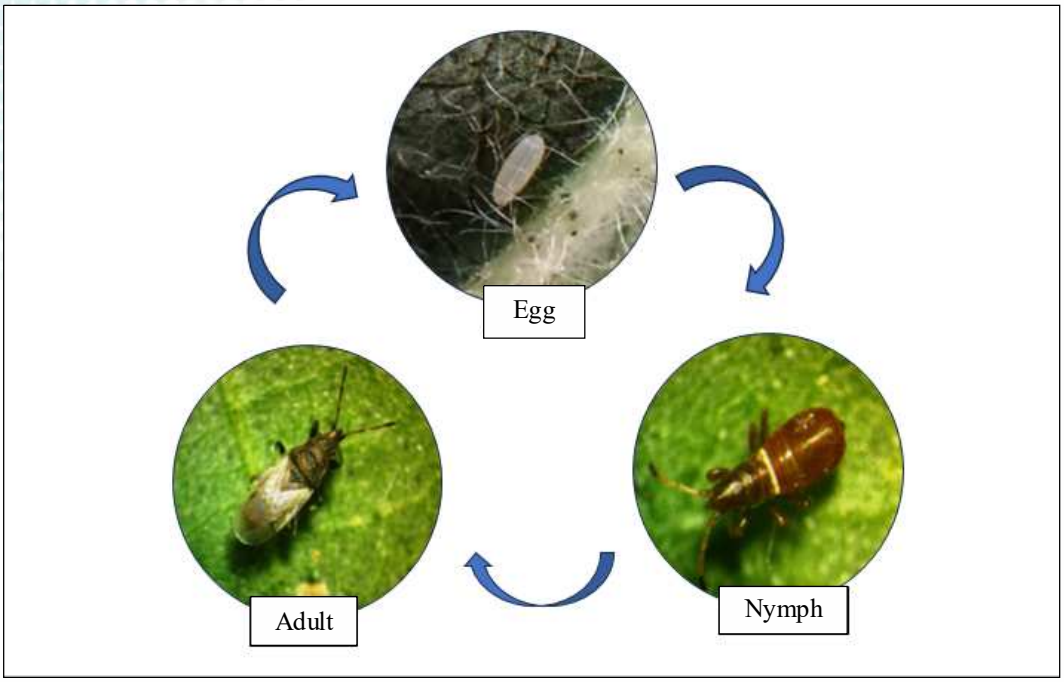


Fig 12. Life cycle of Dusky cotton bug

Management strategy :

Off-season and Pre-sowing management

- **Debris and residue sanitation:** Remove and destroy dry cotton sticks, crop residues, and ginning waste immediately after the previous harvest. This eliminates the primary overwintering and hibernation sites for adult bugs.
- **Alternative host eradication:** Clear fields, bunds, and surrounding areas of alternative malvaceous hosts, specifically Okra (*Abelmoschus esculentus*) and *Hibiscus* spp. to prevent pre-season population buildup.
- **Exploit egg vulnerability:** Since eggs are deposited in exposed areas, utilize thorough field preparation to maximize natural mortality from adverse weather conditions and native soil predators.

Crop growth stage: 0–60 DAS

- At this stage, the bug may begin to appear on buds (squares) and flowers. Neem-based spray recommended for pink bollworm will be useful.
- **Vegetative stage surveillance:** Monitor fields for early immigrant adults moving from off-season reservoirs. The bug remains a minor threat during this period, but maintaining weed-free field boundaries is critical.
- **Natural enemies:** Avoid applying any broad-spectrum chemical insecticides during this window to protect native predatory bugs, spiders, and beetles that feed on early instar dusky cotton bug nymphs.

Crop growth stage: 61–90 DAS

- **Targeted scouting:** Intensify monitoring as the crop transitions to early square and flower formation. Observe closely at buds and floral structures where adult bugs may begin clustering to feed.
- **Botanical sprays:** If bugs begin appearing on squares and flowers, apply 2nd spray of neem-based formulations to suppress initial multiplication without disrupting the field ecology.

Crop growth stage: 91–120 DAS

- **Boll monitoring:** Track population movement on developing green bolls. While the bugs cannot easily puncture hard, un-opened green bolls to damage seed quality, they aggregate in the canopy waiting for the first signs of lint splitting.
- **Strict chemical deferral:** Hold off on broad-spectrum synthetic chemical applications unless other major primary pests (like bollworms) independently cross ET, as dusky cotton bugs do not cause economic seed-staining damage until the bolls actually open.

Crop growth stage: >120 DAS

- **Timely picking:** Practice prompt, regular harvesting of opened bolls. Leaving opened cotton on the plant for extended periods exposes the lint to rapidly expanding bug populations.
- **Post-harvest/storage monitoring:** Continue surveillance during the initial storage phases, as dusky cotton bugs can persist and breed inside seed cotton piles post-harvest.
- **Chemical control:** As of now, label claim insecticides are not available for management of dusky cotton bug, however, as an *ad-hoc* recommendation below mentioned insecticides are suggested for cotton pests can be used in emergency. Chlorpyrifos 20% EC @ 25 mL/10L (1250 mL/ha.) or Profenofos 50%EC @ 30 mL/10L (1500 mL/ha) or Ethion 50 EC @ 40 mL/10L (2000 mL/ha) or Spinetoram 11.70 SC @ 9 mL/10L (450 mL/ha) or Cypermethrin 25% EC @ 4–6 mL (160–280 mL/ha) or Lambda cyhalothrin 5% EC @ 10 mL/10L (500 mL/ha) or Deltamethrin 2.8 EC @ 10 mL (500 mL/ha) or Fenpropathrin 10% EC @ 15-20 mL/10L (750-1000 mL/ha) or Fenvalerate 20% EC @ 10 mL/10L (500 mL/ha).

Natural enemies of pests

Predators

S.No.	Name of natural enemy	Host insects
	Predators	
1.	*Cheilomenes sexmaculata* (Fabricius)	Whitefly, mealybugs, jassids, leafhoppers, mites, and early instar lepidopteran larvae
2.	*Chrysoperla zastrowi silemii*	Aphids, mites, thrips, whitefly, eggs of leafhoppers, *H.armigera*
3.	*Eupeodes confrater* (Wiedemann)	Aphids
4.	*Eocanthocona furcellata* (Wolff)	Larvae of lepidoptera, coleoptera and hemiptera
5.	Predatory spiders	Jassid, aphids, mirids, whitefly and all lepidopteran larvae

S.No.	Name of natural enemy	Host insects
6.	Praying mantids	*H. armigera*
7.	Reduviid bugs	General predators
	Parasitoids	
8.	*Aenasius arizonensis*	*P. solenopsis*
9.	*Acerophagus papayae* Noyes & Schauff	*P. marginatus*
10.	*Aprostocetus* sp.	*P. solenopsis*
11.	*Bracon lefroyi* Dudgeon & Gough	*P. gossypiella*
12.	*Trichogrammatoidea bactrae* Nag	*P. gossypiella*
13.	*Metaphycus* sp.	*P. solenopsis*
14.	*Palexorista laxa* Curran	*H. armigera*
15.	*Rogas aligarhensis* Quadri	*E. vittella*
16.	*Campoletis chlorideae* Uchida	*H. armigera*
17.	*Apanteles angaleti* Muesebeck	*P. gossypiella*
18.	*Microchelonus* spp.	*H. armigera*
19.	*Carcelia illota* Curran	*H. armigera*
20.	*Geocoris* spp.	*H. armigera*

Coccinellid grubs feeding on aphid colony

Adult of Coccinellid

Syrphid maggot feeding on aphid

Chrysoperla adult

Pre season and in-season cultural, mechanical and physical methods for minimizing pest populations

S.No.	Physical/ cultural/ mechanical practices	Target pest(s)	Impact
1	Timely termination of crop	CBW, SBW, PBW	Reduces carry over by breaking cycle of pests
2	Avoid ratoon crop. Allow grazing of cattle, sheep, goat after last picking	MB, PBW	
3	Collection and destruction of bad opened bolls. Destruction of previous season cotton stalk. Do not stack cotton stalks on field bunds	PBW	
4	Install pheromone traps in market yard and ginning mills	PBW	
5	Avoid pre-monsoon sowing	PBW	Adults that emerge from pupae will die for the want of suitable host stage to oviposit and thus it will help reduce population builtup for subsequent generations
6	Growing built-in-refuge (5-10% non *Bt* seeds)	CBW, SBW, PBW	Delay of resistance to *Bt*
7	Destruction of cotton stalk and weeds during off-season and in-season	MB, WF	Reduces carry over pest infestation
8	Growing strips of pigeon pea/ bajra/ sorghum/ maize crop between cotton rows	MB	Act as a physical barrier and check spread
		CBW	Delay in resistance development in CBW. Additionlly help to incresae natural enemies' colonization
9	Destruction of infested plants and weeds	MB	Reduce spread of pest
10	Pre- season deep ploughing	CBW, PBW, TC	Pupal mortality through bird feeding and high temperature
11	Removal of infested terminal shoots	SBW	Reduces infestation
12	Use of sucking pest tolerant genotypes tested and recommended for the agro ecological zone	PBW	To escape from pink bolloworm by avoiding unnecessary sprays for the control of sucking pests.
13	Installation of yellow sticky traps	WF	Monitoring and managing whitefly population

CBW - Cotton bollworm, PBW-Pink bollworm, SBW–Spotted bollworm, TC- Tobacco caterpillar, MB- Mealybug, WF-Whitefy

Economic thresholds (ETs)

Based on the results of field surveys and scouting, farmers are advised to initiate pest management practices immediately once a pest population exceeds the Economic thresholds (ETs). The ETs for major cotton pests are as follows:

Insect	ET : Pest count in a sample of 20 plants per acre
Jassid	2 nymphs per leaf **and /or** 25% plants showing infestation grade II/ III/ IV
Thrips	10 thrips per leaf **and /or** 25% plants showing silvery patches on underside of leaves above mid canopy
Whitefly	6 whitefly/ leaf **and /or** 50% out of 20 observed plants showing sooty mold appearance
Aphids	10% plants showing symptoms cupping / crumpling of few leaves on the upper portion of plant
Mealybugs	5–10% plants showing damage grade II/ III/ IV
Mirid bugs	⩾5 mirid nymphs or adults per plant (from top canopy squares)
Spodoptera	⩾2Egg mass or cluster of gregarious larvae or ⩾10 infested plants (50%) having ⩾5 solitary full-grown larvae / plant
	Bollworms
Cotton bollworm & Spotted bollworm	5-10% infested squares or bolls **and/or** 20% plants having one or more 'flared up' squares
Pink bollworm	Presence of 5-8 moths / trap per night for 3 consecutive nights and or more than 10 % infested flowers or 5-10% green bolls with live larvae

Pictorial representative of sucking pest grades

COTTON JASSID

Grade I

Grade II

Grade 0 : Healthy Plant

Grade I : Entire foliage free from crinkling or curling with no yellowing.

Grade II : Crinkling and curling of few leaves in the lower portion of plant + marginal yellowing of leaves.

Grade III : Crinkling and curling of leaves almost all over the plant. Plant growth hampered.

Grade IV : Extreme curling, crinkling, yellowing, bronzing and drying of leaves.

Grade III

Grade IV

COTTON APHID

Grade I

Grade II

Grade 0 : Healthy Plant

Grade I : Entire plant free from cupping/ crumpling.

Grade II : Cupping / crumpling of few leaves on the upper portion of plant.

Grade III : Cupping of leaves upper leaves and aphid all over the plant.

Grade IV : Extreme cupping, sickness/ sooty mould.

Grade III

Grade IV

THRIPS

Grade I

Grade II

Grade 0 : Healthy Plant

Grade I : No visible symptoms.

Grade II : Silvery patches on underside leaves above mid canopy.

Grade III : Light brown patches visible alongside of veins.

Grade IV : Stiffness of leaves to severe rusty appearance of the crop.

Grade III

Grade IV

COTTON MEALYBUG

Grade I

Grade II

Grade 0 : Healthy Plant

Grade I : About 1-10 mealybugs scattered over the plant.

Grade II : One branch infested heavily with mealybugs.

Grade III : Two or more branches infested heavily with mealybugs, up to 50% plant affected.

Grade IV : Complete plant affected.

Grade III

Grade IV

Pictorial grades reproduced from Nagrare et al., (2019)

CROP WINDOW BASED ADVISORY FOR INSECT PEST MANAGEMENT

Pests	Pest management advisory
Crop growth stage: 0–60 Days After Sowing (DAS)	
Pink bollworm	At 45 DAS, install pheromone traps @5 per ha.
Pink bollworm & sucking pests	Spray NSKE 5% + Azadirachtin 0.15EC @ 5 mL /litre or NSKE / neem oil-based formulation 5 mL /litre (300 or 1500 ppm) + 1.0 mL surfactant) (Initial 1–2 sprays). (NSKE 25L + Azadirachtin 0.15EC 2.5L + 0.5 litres surfactant per ha). Use 150–200 litres of water /acre or 375–500 litres / ha for dilution of the insecticides.
Crop growth stage: 61–90 DAS	
Pink bollworm	Observe for rosette flowers, pluck and destroy them.
	At boll formation stage, farmers are advised to inspect the presence and damage of pink bollworm by plucking and dissecting 20 green bolls from different plants randomly (one boll per plant). If ETL crossed i.e. ⩾ 10% damaged flowers (Rosette flowers) or ⩾10% damaged green bolls (at least two out of 20 bolls having white or pink larvae or exit holes) and or 5–8 moths catch per pheromone trap/AI-Smart trap for consecutive 3 days, spray Profenofos 50%EC @ 30mL/10L (1500 mL/ha) or Emamectin benzoate 5%SG @ 5g/10L (250 g/ha) or Spinetoram 11.70 SC @ 9 mL/10L (450 mL/ha) or Indoxacarb 14.5%SC @ 10 mL /10L (500 mL/ha) or Chlorpyrifos 20 % EC @ 25 mL/10L (1250 mL/ha). (10L= Ten liters of water)
Cotton bollworm and Spotted bollworm	Spray Spinosad 45% SC @ 4 mL/10L (200 mL/ha) or Chlorantraniliprole 18.5% SC @ 3mL/10L (150 mL/ha) or Flubendiamide 39.35%SC @ 2.5 mL/10L (125 mL/ha) or Indoxacarb 14.5%SC @ 10 mL/10L (500 mL/ha).
Cotton Jassid	Spray Flonicamid 50%WG @ 4 g/10L (200g/ha) or Dinotefuran 20%SG @ 3g/10L (150g/ha) or Imidacloprid 17.8%SL @ 3 mL/10L (150 mL/ha) or Tolfenpyrad 15%EC @ 20mL/10L (1000 mL/ha) or Fenpyroximate 5% EC @ 15 mL/10L (750 mL/ha).
Whitefly	Install yellow sticky traps @ 20/ha during July to August for monitoring and @ 100/ha for management. **Insecticides effective against Whitefly adult population:** Diafenthiuron 50%WP @ 12g/10L (600 g/ha) or Afidopyropen 50g/L @ 20mL/10L (1000 ml/ha) or Dinotefuran 20% SG @ 3g/10L (150g/ha) or Flonicamid 50% WG @ 4g/10L (200 g/ha) or Clothianidin 50%WDG 1g/10L (50mL/ha) or Pyrifluquinazon 20% WG@10mL/10L (500mL/ha). **Insecticides effective against the Whitefly nymphs population:** Pyriproxyfen 10% EC @ 20mL/10L (1000 mL) /ha or Buprofezin 25% SC @ 20mL/10L (1000 mL/ha) or Spiromesifen 22.9% SC @ 12mL/10L (600 mL/ha).
Thrips	Spray Thiamethoxam 25%WG @ 2 gm/10L (100g/ha) or Spinetoram 11.7% SC @ 8.4mL/10L (420 mL/ha) or Profenofos 50% EC @ 30mL/10L (1500 mL/ha) or Buprofezin 25% SC @ 20mL/10L (1000 mL/ha).
Sucking pests (Mixed population)	If mixed infestations of **whitefly and thrips** either or both are observed above ET after 60 days old crop, spray Diafenthiuron 50% WP @12g/10L (600g/ha) or Spinetoram 11.7% SC @ 8.4mL/10L (420 mL/ha) or

Pests	Pest management advisory
	Profenofos 50%EC @ 20 mL/10L (1000 ml/ha). If the mixed infestation of **whitefly and cotton jassid** either or both are observed above ET, apply Flonicamid 50% WG @4g/10L (200 g/ha) or Dinotefuran 20% SG @ 3g/10L (150g/ha). **In case sooty mold develops :** Prophylactic/therapeutic sprays of Propiconazole 25%EC @10ml/10L (500mL/ha) at 15 days interval may be applied.
Crop Growth Stage: 91–120 DAS	
Pink bollworm	If ET crossed i.e. >10% damaged flowers (Rosette flowers) or 10% damaged green bolls (at least 1–2 out of 20 bolls having white or pink larvae or exit holes) and or 5–8 moths catch per pheromone trap for consecutive 3 days, release parasitoid *Trichogrammatoidea bactrae* @ 60000 per acre or spray cotton crop with Profenofos 50%EC @ 30 mL/10L (1500 mL/ha) or Emamectin benzoate 5SG @ 5g/10L (250 g/ha) or Spinetoram 11.70 SC @ 9 mL/10L (450 mL/ha) Or Indoxacarb 14.5% SC @10mL/10L (500mL/ha) or Chlorpyrifos 20 % EC @ 25mL/10L (1250 mL/ha). In addition to above, Fipronil 5% EC @40mL/10L (2000mL/ha) is suggested for Central and South India.
Cotton bollworm and Spotted bollworms	For non -Bt/ in *Desi* (*G.arboreum*) cotton, spray Flubendiamide 39.35 SC @ 3mL/10L (150mL/ha) or Indoxacarb 14.5% SC @ 10mL/10L (500 mL/ha) or Spinosad 45% SC @ 4 mL/10L (200 mL/ha)
Jassid, thrips	Spray Thiamethoxam 25%WG @ 2 g/10L (100g/ha) or Tolfenpyrod 15% EC @ 20 mL/10L (1000 mL/ha)
Thrips	Spray Thiamethoxam 25%WG @ 2 g/10L (100g/ha) or Spinetoram 1.7% SC @ 8.4 mL/10L (420 mL/ha)
Whitefly	**In North zone** **For whitefly adult control:** Spray Diafenthiuron 50% WP @ 12g/10L (600 g/ha) or Afidopyropen 50 g/L @ 20ml/10L (1000 mL/ha) or Dinotefuran 20% SG @ 3g/10L (150g/ha) or Flonicamid 50%WG @ 4g/10L (200 g/ha) or Clothianidin 50%WDG @ 1g/10L (50g/ha) **For whitefly nymph control:** Spray Pyriproxyfen 10%EC@ 20ml/10L (1000 mL/ha) or Buprofezin 25% SC @ 20mL/10L (1000 mL/ha) or Spiromesifen 22.9% SC @ 12mL/10L (600 mL/ha). **In Central and South zones** Spray Dinotefuran 20SG @ 3g/10L (150g/ha) or Spiromesifen 22.9% EC @12mL/10L (600 mL/ha) or Pyriproxyfen 10EC @ 20mL/L (1000 mL/ha) or Diafenthiuron 50%WP @ 12g/10L (600 g/ha) or Profenofos 50 EC @ 30mL/10L (1500mL/ha) or Pyrifluquinazon 20% WG @ 10mL/10L (500 mL/ha).
Crop Growth Stage: >120 DAS	
Pink bollworm	Spray Cypermethrin 10%EC @ 10–15mL/10L (550–760 mL/ha) or Cypermethrin 25% EC @ 4–6 mL (160–280 mL/ha) or Lambda cyhalothrin 5% EC @ 10mL/10L (500 ml/ha) or Deltamethrin 2.8 EC @ 10 mL (500 mL/ha) or Fenpropathrin 10% EC @ 15–20mL/10L (750–1000 mL/ha) or Fenvalerate 20% EC @ 10mL/10L (500 mL/ha) or Alphacypermethrin 10% SC @ 6mL/10L (250–300 mL/ha).

Pests	Pest management advisory
Crop Growth Stage: 180 DAS	
	▪ Terminate the crop as early as economically feasible. For this purpose, give last irrigation by end of September in case of North zone. It would reduce bollworms damage and their carryover to the next cropping season. ▪ Allow animals grazing in the field after picking to reduce the carryover of bollworms. ▪ Stack cotton stalks away from the field vertically. If possible, shredding of cotton stalks in soil is advisable.

Recommendations of the insecticides are subjected to the guidelines of CIB&RC.

Do not repeat same insecticide more than twice.

Cotton diseases and their management

Severity of cotton diseases in cotton growing zones of India

Bacterial blight, Internal boll rot, Root rot, *Fusarium* wilt, Target spot, Grey mildew, Cotton leaf curl disease, Tobacco streak virus are major diseases of cotton. Zone wise their occurrence and economic importance is given in Table 5.

Table 5. Zone wise Disease of cotton and their economic importance

S.No.	Name of disease	Zone wise occurrence and economic importance		
	Bacterial disease	**North**	**Central**	**South**
1.	Bacterial blight: *Xanthomonas citri* pv. *malvacearum*	Minor	Major	Major
2.	Internal boll rot disease: *Pantoea* spp.	Moderate	Major	Moderate
	Fungal diseases			
3.	*Alternaria* leaf spot: *Alternaria* spp.	Minor	Major	Moderate
4.	*Myrothecium* leaf spot: *Myrotheceum roridum*	Minor	Minor	Minor
5.	Root rot: *Rhizoctonia solani, Macrophomina phaseolina, Sclerotium* spp.	Major	Minor	Moderate
6.	*Fusarium* wilt: *Fusarium oxysporum* f.sp. *vasinfectum*	Major	Major	Major
7.	*Verticillium* wilt: *Verticillium dahliae* and *Verticillium albo-atrum*	-	Minor	Minor
8.	Target spot*: Corynespora cassiicola*	Moderate	Major	Moderate
9.	Grey mildew: *Ramulariopsis gossypii* and *R. pseudoglycines* (formerly *Ramularia areola*)	-	Major	Major
10.	Leaf rust: *Phakopsora gossypii*			Moderate
11.	*Helminthosporim* leaf spot: Helminthosporium *gossypii*, *H. spiciferum*	-	-	Minor
12.	Cercospora leaf spots: *Cercospora gossypina*	Minor	Minor	Minor
13.	Anthracnose: *Colletotrichum gossypii, C. siamense*	-	-	Minor
14.	Phomopsis leaf spot/blight: *Phomopsis gossypii*	-	Moderate	-
15.	Fungal boll rot disease: Several fungal species	Moderate	Moderate	Moderate
	Viral diseases			
16.	Cotton leaf curl disease (CLCuD)	Major	-	-
17.	Tobacco Streak Virus (TSV)	Minor	Moderate	Major

Mode of disease spread

Mode of disease spread through seeds, seedling, soil and wind is given in Table 6.

Table 6. Important diseases of cotton in India and their mode of spread

S.No.	Name of disease and Scientific name	Mode of disease spread			
		Seed borne	Seedling disease	Soil borne	Foliar disease
	Bacterial disease				
1.	Bacterial blight: *Xanthomonas citri* pv. *malvacearum*	√	√	-	√
2.	Internal boll rot disease (*Pantoea* spp.)	-	-	-	√
	Fungal diseases				
3.	*Alternaria* leaf spot: Alternaria spp.	√	√	√*	√
4.	*Myrothecium* leaf spot: *Myrotheceum roridum*	√	-	√*	√
5.	Root rot: *Rhizoctonia solani, Macrophomina phaseolina, Sclerotium* spp.	-	√	√*	-
6.	*Fusarium* wilt: *Fusarium oxysporum* f.sp. *vasinfectum*	√	-	√*	√
7.	*Verticillium* wilt: *Verticillium dahliae* and *Verticillium albo-atrum*	√	√	√*	√
8.	Target spot*: Corynespora cassiicola*	√	√	√*	√
9.	Grey mildew: *Ramulariopsis gossypii* and *R. pseudoglycines* (formerly *Ramularia areola*)	√	-	√*	√
10.	Leaf rust : *Phakopsora gossypii*			√*	√
11.	*Helminthosporim* leaf spot: *Helminthosporium* spp.	√	√	√*	√
12.	Cercospora leaf spot: *Cercospora gossypina*	-	√	√*	√
13.	*Anthracnose: Colletotrichum gossypii or C. siamense*	√	√	√*	√
14.	Phomopsis leaf spot/blight: *Phomopsis gossypii.*	-	√	√*	√
15.	Fungal boll rot disease: Several fungal species	-	-	-	√
	Viral diseases				
16.	Cotton leaf curl disease (CLCuD)	-	-	-	√ #
17.	Tobacco Streak Virus (TSV)	-	-	-	√ #

* The pathogen survives in soil on plant debris

√# Insect-vector transmitted disease, virus survives in alternate hosts during off season

Economic important diseases in cotton growing zones and primary impact

Crop growth stage economic important diseases in coton growing zones and primary impact is given in Tables 7–9.

Table 7. Economic important diseases in North zone and primary impact

Crop stage	Dominant disease	Risk level	Primary impact
1. Germination & Seedling (1–20 Days)	Bacterial blight	Low	Not much impact
	Root rot	High	High plant mortality in severely infected fields
2. Vegetative Growth (20–45 Days)	Bacterial blight	Low	Not much impact
	Root rot	High	High plant mortality in severely infected fields
	Fusarium wilt	Moderate	Plant mortality in infected fields and reduced plant stand
	Target spot	Moderate	Leaf defoliation
	CLCuD	High	Reduced plant growth and yield
	TSV	Low	Not much impact
3. Squaring (Pre-flowering) (45–70 Days)	Bacterial blight	Low	Not much impact
	Root rot	High	High plant mortality in severely infected fields
	Fusarium wilt	Moderate	Plant mortality in infected fields and reduced plant stand
	Target spot	Moderate	Leaf defoliation
	CLCuD	High	Reduced plant growth and yield
	TSV	Low	Not much impact
4. Flowering & Boll Setting (70–120 Days)	Bacterial blight	Low	Not much impact
	Internal boll rot disease	Low	Not much impact
	Myrothecium leaf spot	Low	Not much impact
	Root rot	High	High plant mortality in severely infected fields
	Fusarium wilt	Moderate	Plant mortality in severely infected fields
	Target spot	Moderate	leaf defoliation
	CLCuD	High	Reduced yield
	TSV	Low	Not much impact
5. Boll Development/ Maturity (120–150 Days)	Bacterial blight	Low	Not much impact
	Internal boll rot disease	Low	Not much impact
	Myrothecium leaf spot	Low	Not much impact
	Root rot	High	High plant mortality in severely infected fields
	Fusarium wilt	Moderate	Plant mortality in infected fields

Crop stage	Dominant disease	Risk level	Primary impact
	Target spot	Moderate	leaf defoliation
	Boll rot (external)	Moderate	Lint quality deteriorates
	CLCuD	High	Reduced yield
	TSV	Low	Not much impact
Harvesting (150–180 Days)	Boll rot (external)	Moderate	Lint quality deteriorates

Table 8. Economic important diseases in Central zone and primary impact

Crop stage	Dominant disease	Risk level	Primary impact
1. Germination & Seedling (1–20 Days)	Root rot	Moderate	Poor plant stand
2. Vegetative growth (20–45 Days)	Bacterial blight	Moderate	Leaf defoliation
	Alternaria leaf spot	Moderate	Leaf defoliation
	Root rot	Moderate	Poor plant stand
	Fusarium wilt	Moderate	Poor plant stand
	Target spot	Moderate	Leaf defoliation
	Phomopsis leaf spot/blight	Low	Leaf defoliation
	TSV	Low	Square drying, poor boll setting
3. Squaring (Pre-flowering) (45–70 Days)	Bacterial blight	Moderate	Leaf blighting, defoliation
	Alternaria leaf spot	Moderate	Leaf blighting, defoliation
	Root rot	Moderate	Poor plant stand
	Fusarium wilt:	Moderate	Poor plant stand
	Target spot	Moderate	Leaf defoliation
	Grey mildew	Low	Leaf defoliation
	Phomopsis leaf spot/blight	Low	Leaf blighting, defoliation
	TSV	Moderate	Square drying, stunted growth and poor boll setting
4. Flowering &boll Setting (70–120 Days)	Bacterial blight	Moderate	Leaf blighting, defoliation
	Internal boll rot disease	High	Yield and quality
	Alternaria leaf spot	Moderate	Leaf blighting, defoliation
	Myrothecium leaf spot	Low	Not much impact
	Root rot	Moderate	Reduced plant stand
	Fusarium wilt	Moderate	Poor plant stand
	Target spot	Moderate	Leaf defoliation
	Grey mildew	Moderate	Leaf defoliation
	Boll rot (external)	Moderate	Lint quality affected
	TSV	Moderate	Square drying, stunted growth and poot boll setting

Crop stage	Dominant disease	Risk level	Primary impact
5. Boll development/ maturity (120–150 Days)	Bacterial blight	Moderate	Leaf defoliation
	Internal boll rot disease	High	Yield and quality
	Alternaria leaf spot	Moderate	Leaf defoliation
	Myrothecium leaf spot	Low	Not much impact
	Fusarium wilt:	Moderate	Poor plant stand, low yield
	Target spot	Moderate	Leaf defoliation, yield reduction
	Grey mildew	Moderate	Leaf defoliation, yield reduction
	Boll rot (external)	Moderate	Lint quality affected
Harvesting (150–180 Days)	Grey mildew	Moderate	Yield reduction
	Boll rot (external)	Moderate	Lint quality affected

Table 9. Economic important diseases in South zone and primary impact

Crop stage	Dominant disease	Risk level	Primary impact
1. Germination & Seedling (1–20 Days)	Root rot	Low	Poor plant stand
2. Vegetative growth (20–45 Days)	Bacterial blight	Moderate	Leaf defoliation
	Alternaria leaf spot	Moderate	leaf defoliation
	Root rot	Low	Poor plant stand
	Verticillium wilt	Low	Poor plant stand
	Target spot	Low	Leaf spots, defoliation
	TSV	Low	Square drying, stunted growth and poor boll setting
3. Squaring (Pre-flowering) (45–70 Days)	Bacterial blight	Major	Leaf blighting, defoliation
	Alternaria leaf spot	Moderate	Leaf blighting, defoliation
	Root rot	Low	Poor plant stand
	Verticillium wilt	Low	Reduced plant stand
	Target spot	Low	Leaf defoliation
	Grey mildew	Low	Leaf defoliation
	Leaf rust	Low	Photosynthesis affected
	TSV	Low	Square drying, stunted growth and poor boll setting
4. Flowering & boll Setting (70–120 Days)	Bacterial blight	Major	Leaf defoliation
	Internal boll rot disease	Moderate	Yield and quality deteriorate
	Alternaria leaf spot	Moderate	leaf defoliation
	Root rot	Low	Reduced plant stand
	Verticillium wilt	Low	Reduced plant stand

Crop stage	Dominant disease	Risk level	Primary impact
	Target spot	Low	Leaf defoliation
	Grey mildew	Moderate	Leaf defoliation
	Leaf rust	Low	Photosynthesis affected
	Helminthosporim leaf spot	Low	Not much impact
	Cercospora leaf spot	Minor	Not much impact
	Anthracnose	Low	Not much impact
	Boll rot (external)	Low	Lint quality deteriorates
	TSV	Low	Square drying, stunted growth and poor boll setting
5. Boll development/ maturity (120–150 Days)	Bacterial blight	Major	Yield reduction
	Internal boll rot disease	Moderate	Yield and quality deteriorate
	Alternaria leaf spot	Moderate	leaf defoliation
	Root rot	Low	Poor plant stand
	Verticillium wilt	Low	Poor stand
	Target spot	Low	Leaf defoliation
	Grey mildew	Moderate	Leaf defoliation
	Leaf rust	Low	Photosynthesis affected
	Helminthosporim leaf spot	Low	Not much impact
	Anthracnose	Low	Not much impact
	Boll rot (external)	Low	Lint quality deteriorates
Harvesting (150–180 Days)	Grey mildew	Moderate	Leaf defoliation
	Leaf rust	Low	Photosynthesis affected

Cotton diseases and management strategy

1. ROOT ROT

National importance: Root rot is a highly destructive soil-borne disease that targets the plant's vascular system. Unlike foliar diseases that only damage leaves, root rot cuts off the plant's water and nutrient supply, leading to rapid wilting and complete plant death. The disease is widespread across key Indian states, including Punjab, Haryana, Rajasthan, Gujarat, Bihar, Andhra Pradesh, and Tamil Nadu. Both Upland and *Desi* cotton varieties are vulnerable, though *Desi* cotton is documented to be far more susceptible (Monga et al., 1997).

Causal organism: *Rhizoctonia solani, Macrophomina phaseolina, Sclerotium rolfsii*

Economic impact: While average annual yield losses due to cotton diseases hover around 10–15%, severe root rot outbreaks in endemic zones (such as the North zone in India,

Haryana, Punjab, Rajasthan) can cause up to 50% or total crop failure in localized pockets.

Disease symptoms: Plants suffering from root rot disease exhibit wilting and drooping leaves, and because the infected plant lack secondary roots, they can be effortlessly uprooted. While root discoloration is a universal symptom, the specific visual cues help differentiate the underlying pathogens. For instance, *R. solani* infection produce brown and wet roots, whereas *M. phaseolina* causes distinctly black, dry, and bark shredding. Conversely, *Sclerotium rolfsii*, can be identified by the formation of spherical sclerotial bodies on infected plants and in lab cultures. Regardless of the specific fungus, the disease can cause outbreaks under high temperature and excess soil moisture conditions (Kirkpatrick and Rothrock, 2001).

Root rot infected cotton seedlings

Root rot infected cotton seedlings

Root rot infected cotton plant

Root rot infected *Desi* cotton field

Seasonal disease incidence: Low to moderate incidence can be observed at seedling stage, moderate to high in vegetative stage while maximum seasonal peak in flowering and boll formation stage.

Disease cycle and epidemiology: Warm and moist soil conditions favour disease development. The fungi survive between cropping seasons primarily such as sclerotia and chlamydospores that are hard, compact, protective bundles of dark fungal hyphae that act like armor. Sclerotia reside 15 to 30 cm deep in the soil profile or nestled within infected cotton stalks left over from the previous harvest. Sclerotia can survive dry summer fallows,

withstand extreme soil temperatures up to 60 ºC and remain viable in a dormant state for several years without a host plant. When the new crop is sown and environmental conditions become favourable, the cycle reactivates. Soil temperatures rising between 35 ºC and 39 ºC, coupled with intermittent moisture, signal the sclerotia to wake up. The sclerotia germinate, sending out fine thread-like structures called hyphae. These hyphae grow freely through the soil pore spaces until they sense chemical signals emitted by the roots of a nearby cotton plant. The hyphae latch onto the cotton taproot and lateral root systems, entering either through natural growth cracks, microscopic wounds, or by directly dissolving the root's outer cell walls using specialized fungal enzymes. Once inside, the fungus transitions from a soil dweller into an aggressive systemic parasite. The hyphae rapidly multiply inside the plant's xylem tissue. As the fungal mass thickens, it physically plugs the xylem tubes and secretes toxins that cause the root cortex to collapse. This results in the characteristic symptoms of wet/brown decay in *R. solani* or dry/black decay accompanied by severe bark shredding in *M. phaseolina*. Because the root system can no longer absorb water, the plant experiences rapid, acute dehydration. During peak heat, the entire cotton plant suddenly and permanently wilts in a matter of 24–48 hours, leaving dead, brittle leaves still firmly stuck to the branches (Sain et al., 2023)

Disease surveillance: At seedling stage, inspect weekly during early morning. Focus on seedling emergence gaps or "damping-off". At vegetative and boll formation stage and right after early heavy rains or irrigation cycles when high temperatures compress soil, walk the field in a 'X' or 'Z' pattern every 3–5 days. Pay special attention to low-lying, poorly drained, or heavily compacted areas where moisture pools. Examine root, gently shake loose dirt off the roots. Check for absence of lateral/secondary roots, easily peeling bark, and brown/wet or black/dry discoloration. The disease severity is equal to the percentage of number of plant wilted/died.

Economic threshold: 2–5% disease incidence.

Management strategy:

Before sowing

- **Deep summer ploughing:** Carry out deep summer ploughing; collect and destroy infected crop residues from the field to expose pathogens to solar heat.
- **Crop rotation:** Do not cultivate cotton continuously in fields previously affected with root rot; instead, follow appropriate crop rotation practices with non-host crops.
- **Organic soil enrichment:** During field preparation, apply *Trichoderma* spp. (1% WP) @ 10 kg mixed with 200 kg well-decomposed Farm Yard Manure (FYM) per hectare uniformly in the field.
- **Seed selection and seed dressing:** Always use resistant/tolerant varieties/hybrids, healthy and treated seeds. Seed treatment before sowing should be carried out strictly in the order of fungicide → insecticide → bioagents. Treat seeds with Thiram 75% WS @ 3 g/kg seed or Tetraconazole 11.6% w/w (12.5% w/v) SL @ 1.5 mL/kg or Sedaxane 2.5% + Fludioxonil 2.5% + Thiamethoxam 26.25% @ 4 mL/kg or

Carboxin + Thiram 7.5 WS @ 3.5 g/kg seed and *Trichoderma harzianum / T. viride* 1% WP @ 5 g/kg seed.

Crop growth stage: 0–60 DAS

- **Judicious fertilizer use:** Avoid excessive application of nitrogenous fertilizers, as excessive vegetative growth increases moisture and nutrient stress, creating microclimates that favour root rot development.
- **Moisture regulation:** Irrigate the crop whenever necessary to avoid moisture stress, as dry-spells followed by sudden wetness can trigger the disease.
- **Rogueing:** Remove and destroy infected plants immediately after the appearance of early symptoms to prevent the subterranean spread of the fungus.
- **Root drenching:** If disease incidence is noticed, immediately apply *Trichoderma* formulation @ 50 g or Carbendazim 50% WP @ 10 g/ 10 L water through drenching or drip application directly near the root zone of infected and surrounding plants.

Crop growth stage: 61–90 DAS

- **Stress management :** Continue to irrigate the crop efficiently. This phase often coincides with peak vegetative growth or flowering, where moisture stress heavily accelerates root rot.
- **Sanitation :** Constantly monitor the field, promptly remove and destroy any newly infected plants to safeguard neighbouring healthy cotton crops.
- **Root drenching :** If the disease spreads or emerges in new patches, repeat the drenching of Carbendazim 50% WP @ 10 g/10 L water or *Trichoderma harzianum / T. viride* 1% WP @ 50 g/10 L water around the infected root zones.

Crop growth stage: 91–120 DAS

- **Spot drenching:** Continue monitoring for late-season wilting. Apply the root zone drenching mix of *Trichoderma* or Carbendazim 50% WP exclusively to affected pockets to minimize late-stage crop loss.
- **Water management:** Maintain regular, controlled irrigation intervals to prevent soil cracking, which can damage roots and provide easy entry points for fungal spores.

Crop growth stage: >120 DAS

- **Residue shredding:** Post-harvest cotton stalks and plant residues should be shredded using a tractor-operated shredder.
- ***In-situ* biological decomposition :** Treat the shredded material by spraying with *Trichoderma harzianum* or *T. viride* @ 5 g/L and incorporate it back into the soil to promote rapid decomposition and outcompete residual root rot inoculum.

2. FUSARIUM WILT

National importance : The disease has historical and ongoing significance, it poses major

recurring threats across heavy clay soils and loamy regions, including parts of Maharashtra, Tamil Nadu, and Gujarat. Mostly affects Asiatic cottons (*G. arboreum* and *G. herbaceum*). However, recently the *Fusarium* wilt has been reported to cause disease in *G. hirsutum* in North India and is posing threat to cotton production.

Causal organism : *Fusarium oxysporum* f. sp. *vasinfectum*

Economic impact : Disease triggers yield losses ranging from 10–50%.

Disease symptoms : *Fusarium* wilt infection can occur at any time from vegetative growth through boll development. Wilt symptoms can appear as early as the seedling stage, beginning with necrotic spots on the cotyledons before spreading to new leaves as net-like necrosis along the veins. Infection can take place anytime from vegetative growth through boll development. As the disease progresses, affected plants show distinct leaf yellowing, wilting, and drooping, which eventually leads to the partial or complete drying out of the plant. Longitudinally cuts of roots, stems, or petioles reveals dark brown discoloration of the internal vascular tissue, the most characteristic diagnostic symptom of the disease. Additionally, nematode infestation can wound the roots, trigger secondary infection and significantly increase wilt severity throughout the season (Sain et al., 2023).

Vascular discoloration of Fusarium wilt infected root

Wilt infected Upland cotton plant

Vascular discoloration of Fusarium wilt infected Upland cotton stem

Wilt infected *Desi* cotton plant

Seasonal disease incidence: The disease can be noticed starting from seedling to harvest stage however, peak incidence can be observed during peak flowering & boll development stage.

Disease cycle and epidemiology: The life cycle of *Fusarium* wilt begins in the soil, where the pathogen survives between seasons inside infected crop debris as tough, resting structures called chlamydospores. When soil temperature and moisture levels become favourable, these spores germinate and invade the root systems of newly planted cotton. Once inside, the fungus climbs into the plant's vascular tissues and rapidly multiplies. This internal growth blocks the upward movement of water and nutrients, causing the classic symptoms of vascular browning, leaf yellowing, severe wilting, and complete plant death. Throughout its lifecycle, the fungus produces three spore types, microconidia for internal spread, macroconidia on dead tissue, and chlamydospores for long-term survival. The disease is easily introduced to new fields through infected seeds, contaminated farm machinery, and leftover crop residues, starting the new cycle.

Disease surveillance: Walk standard 'X' or 'Z' pattern through the field. During seedling stage walk the fields to look for damping-off. At squaring to peak flowering increase the field scouting to twice a week during early morning or late evening, especially when afternoon temperatures rise above 28 °C and plants face high water demands. Scan the canopy for patches of yellowing, stunted growth, or wilting. Fusarium wilt rarely strikes a single plant uniformly; it typically radiates outward in distinct, irregular clusters or hot spots along a row. The disease severity is equals to the percentage of number of plant wilted/died.

Economic threshold: 2–5% disease incidence.

Management strategy:

Crop growth stage: 0–60 DAS

- **Seed treatment:** Ensure seeds are treated with a bio-fungicide like *Trichoderma harzianum* / *T. viride* @ 4 g/kg seed or Sedaxane 2.5% + Fludioxonil 2.5% + Thiamethoxam 26.25% @ 4mL/kg or Carboxin 37.5% + Thiram 37.5% WS @ 3.5 g/kg or Thiram 75% WS @ 3 g/ kg of seeds or *Trichoderma harzianum*/ *T. viride* @ 5 g/L. On appearance of symptoms soil drenching with Carbendazim 50 WP@ 1 g/L water is suggested.
- **Soil amending:** Apply FYM enriched with *Trichoderma* spp. (1% WP) @ 10 kg mixed with 200 kg well-decomposed Farm Yard Manure (FYM) per ha at the time of sowing. This builds a biological shield around emerging roots.
- **Nematode check:** Keep a strict eye out for root-knot nematodes. Nematode feeding creates open wounds on the roots, acting as an open doorway for *Fusarium*.
- **Drainage:** Avoid waterlogging in the early days. Excessive water slows root growth and creates the perfect environment for fungal spore germination.

Crop growth stage: 61–90 DAS

- **Soil drenching:** If early symptoms of yellowing between leaf veins appear in patches, drench the soil around affected and neighbouring healthy plants with Carbendazim 50 WP @ 1 g/L water.

- **Balanced nutrition:** Avoid heavy applications of Nitrogen, which produces lush, weak tissue susceptible to the fungus. Instead, optimize Potassium levels; high potassium strengthens cell walls and helps the plant maintain internal water pressure despite vascular stress.
- **Sanitation:** Carefully uproot and destroy severely wilted plants to prevent them from dropping millions of long-term survival Chlamydospores back into soil.

Crop growth stage: 91–120 DAS

- **Moisture management:** Maintain consistent, moderate soil moisture. Avoid alternate severe drying and heavy flooding, which causes root stress and accelerates vascular collapse.
- **Foliar sprays:** If the roots are partially damaged by the fungus, uptake of soil nutrients drops. Apply mild foliar sprays of macro/micronutrients or potassium nitrate to feed the plant directly through the leaves.
- **Tool hygiene:** If moving machinery or tools between fields, wash them thoroughly. Soil sticking to tractors or boots is the primary way of Fusarium spreads to clean plots.

Crop growth stage: >120 DAS

- **Residue management:** Do not incorporate heavily infected crop residue straight into the soil right after harvest. Leave it exposed on the surface to dry out, or safely remove and burn infected stalks.
- ***In-situ* pathogen inoculum management:** Treat the shredded material with *Trichoderma harzianum* or *T. viride* @ 5 g/L and incorporate it back into the soil to promote rapid decomposition and reduce pathogens inoculum.
- **Crop rotation:** Fusarium spores can survive in the soil for years; crop rotation may be followed. Rotate the field with non-host crops like maize, sorghum, or paddy for at least 2–3 seasons to naturally starve out the remaining soil population.

3. INTERNAL BOLL ROT DISEASE

National importance : In recent years, the emergence of internal boll rot disease caused by certain bacterial species has become a highly significant economic concern in India. Since, the bacteria causes internal necrosis of the developing lint and cotton seeds, it directly affects lint quality and seed viability. For India's robust cotton seeds production industry, an outbreak of internal bacterial boll rot dramatically reduce the germination percentage of harvested seeds, leading to severe financial losses for seed producers and breeders. The disease is emerging and prevalent in all the three cotton-growing zones of India (Nagrale et al., 2020).

Causal organism(s): *Pantoea dispersa* and other *Pantoea* spp.

Economic impact: Yield losses up to 25% caused by internal boll rot disease has been reported which resulted in severe economic losses and yield reduction to cotton production (Fand et al., 2025).

Disease symptoms: Externally, the developing green bolls appears firm and deceptively normal without any distinct lesions, dark spots, insect damage or fungal growth on the outer boll surface. The infection is often localized, restricted to just one or two locules. The developing lint within the infected locule changes from its pearl-white to a light yellow, dark brown, or brick colour. During high relative humidity conditions, the infected immature lint and seeds turns into a wet, slimy, or macerated mass. They become swollen, and develop dark, necrotic patches until the seeds and boll tissues completely rots. Further, the infected lint and seeds may results in "hardlock" condition of developing bolls, sometimes partially locules opened or remain tightly compacted together and dry (Nagrale et al., 2020).

Lint and seed rot caused by bacterial infection in green bolls

Necrosis lint and seed rot by bacterial infection

Locular symptom of bacterial seed rot

Boll rot by bacterial infection

Seasonal disease incidence: Maximum disease incidence seen during peak boll development phase. This is the high-risk window for internal boll disease. Dense crop canopy, hot and humid conditions inside the lower rows, create favourable microclimate. In Central India, October heat increase soil and air temperatures, providing an ideal temperature for phytopathogenic bacteria present inside the bolls. The bacterial colonies multiply exponentially inside the locular section, producing developing lint into a wet, yellow-to-reddish slimy appearance.

Disease cycle and epidemiology: Plant pathogenic *Pantoea dispersa* and other *Pantoea* spp. are the opportunistic, facultative and nonspore forming bacteria. However, it survives

quietly within the tissue or root zones of local perennial weeds, alternate hosts, and leftover unpulled crop debris; under field or crop debris during the off-season. The piercing sap sucking insects vectoring the *Pantoea* spp. on their stylets to healthy bolls. During feeding, insect vector punctures a tender, developing green boll (typically 2–3 weeks old) to suck nutrients from the succulent bolls and young seeds, thus injecting bacterial cells directly into the soft internal bolls tissues. After entering the bacteria inside the high-moisture, nutrient-rich inner area of boll locule and tissues, the bacteria populations multiply rapidly. The bacterial population secretes enzymes that break down the delicate cell structures of the developing lint fibers, turning the young white lint into a wet, slimy, yellow-to-reddish mass. The internal rot leading to seed abortion, discolouration, and localized tissue necrosis inside the affected boll locules. The irrigation water, rain splashes, and stormy weather help to disseminate the bacteria to healthy plants by facilitating secondary infection.

Disease surveillance: Collect randomly about 20 green bolls in an acre and cut open to observe for localized yellow, dark brown, or red-tan discolouration of internal boll and locular tissues. In mid to late crop growth phases, the developing fibre and locular seed produce yellow to brown lint rot, swollen seeds and internal necrosis.

Economic threshold: 25% infected bolls

Management strategy:

Crop growth stage: 0–60 DAS

- **Plant spacing:** Maintain optimum plant spacing as per soil type and select a suitable cultivar or hybrid to ensure proper aeration within the crop canopy.
- **Nutrient management:** Avoid excessive use of Nitrogen and Phosphorus fertilizers, as they boost overgrowth.
- **Canopy management:** Prevent excessive vegetative or rank growth and manage the canopy through suitable crop and nutrient application practices.
- **Drainage management:** Avoid water stagnation and waterlogging conditions in the field. Remove excess water from the field through proper drainage facilities or trenches.
- **Vector management:** Monitor the infestation of piercing-sap-sucking insects such as thrips, leafhoppers, and stink bugs during squaring, early flowering and boll developmental stages. Manage these insect vectors by spray application of Spinetoram 11.7% SC @ 8.4 mL, Profenofos 50% EC @ 30 mL, or Dinotefuran 20 SG @ 3 g / 10 Litres of water.

Crop growth stage: 61–90 DAS

- **Vector management:** Continue monitoring and managing sucking insect vectors (thrips, leafhoppers, stink bugs, and early red cotton bugs) to prevent them from puncturing the young and tender green bolls.
- **Prophylactic sprays:** Apply preventative foliar sprays (carbendazim 12% +

mancozeb 63% WP@ 25–30 g or propineb 70% WP@ 25 g per 10 litres of water) during flowering and early boll development phase on the basis of congenial weather conditions (high humidity or intermittent rains).

Crop growth stage: 91–120 DAS

- **Foliar nutrition:** Apply phosphorus and potash fertilizers through (19:19:19) foliar application during boll development stages to improve overall crop health and disease resistance.
- **Disease protection:** Continue with scheduled prophylactic foliar sprays based on weather factors to protect late-set bolls from the internal rot disease.
- **Sucking pest control:** Manage sap sucking insect vector to minimize fresh transmission of bacterial entry through injuries to green bolls.

4. FUNGAL BOLL ROT DISEASE

National importance: Fungal boll rot disease has rapidly emerged as a serious threat to cotton production in all the three cotton-growing zones of India. Fungal boll rot pathogens cause necrosis of boll surface tissues and yellowing of infected fibre, browning, and rotting.

Causal organisms: *Lasiodiplodia theobromae, C. gloeosporioides*, *Phytophthora* spp., *P. boehmeriae*, *Corynespora cassiicola*, *Myrothecium roridum*, *Aspergillus flavus*, *Nigrospora oryzae, Alternaria macrospora*, *A. alternata*, *A. gossypina*, *Botryodiplodia theobromae*; *Ascochyta gossypii, Ramularia areola*, *Penicillium* spp., *Mucor* spp., *Cercospora* spp., *Cladosporium* spp., *Botrytis* spp., *Cephalosporium* spp., *Curvularia* spp., and *Epicoccum* spp., *Phoma exigua*, *Phomopsis* spp., *Rhizoctonia solani* (Taneja, 1988; Guthrie et al., 1994; Watkins, 1981; Srinivasan, 1994; Batson, 2001; Belot and Zambiasi, 2007; Zancan et al., 2011; Zancan et al., 2013).

Economic impact: Exacerbated by cloudy, high-humidity weather or rain splashes during flowering/boll formation stages, boll rot may cause potential yield losses of up to 20–25%.

Disease symptoms: Fungi infect the developing and partially opened bolls, leads to rotting of the boll tissues, developing fibres and the lint. Under favourable environmental conditions, the necrotic lesions and fungal mycelia growth may commonly be noticed on the infected and diseased bolls.

Seasonal disease incidence: Prolonged or drizzling rainfall and rain splashes, warm temperatures, poor drainage or waterlogged conditions of fields, dense canopy and high relative humidity make congenial conditions for development and spread of the fungal boll rot disease. The disease generally starts from lower canopy, during partial opening, and spreads to maturity boll stages.

Disease cycle and epidemiology

The initial inoculums or propagules of the fungal boll rot pathogens may originate from infected seeds, crop debris, plant residues, infested soil and weeds, alternate or collateral hosts. These pathogens may enter the boll through natural opening like stomata, nectaries,

sutures, calyx, pedicel, peduncle or wounds caused by insects or any other physical damage to bolls. Most of the fungal pathogens are "primary invaders" and can directly penetrate the boll wall, whereas some opportunistic or saprophytic pathogens require injury or wounds for the entry or successful infection to bolls. Some dominant pathogens such as *L. theobromae*, *Alternaria* spp., *Fusarium* spp., and *Colletotrichum* spp. frequently cause severe fungal boll rots which produce disease like *Diplodia* boll rot, anthracnose boll rot and *Fusarium* boll rot, particularly under wet and humid field conditions. Some species of *Fusarium* including *F. oxysporum, F. moniliforme* and *F. roseum* are capable of infection to healthy, uninjured bolls, however other *Fusarium* spp. requires wounds or insect damage for infection. In India, boll rot caused by *A. macrospora* was reported by Perane et al., (2015).

Lesions on boll surface by fungal pathogens

White mycelial growth of fungus on boll surface

Boll infection by molds and secondary invaders

Necrosis, white mycelia growth and progression of fungal pathogen on boll

Disease surveillance: Fungal boll rot surveillance requires a dynamic approach because the symptoms initially appear at lower canopy bolls which further progress to upper parts with favourable environmental conditions of high humidity, warm temperature and dense canopy. Since, both primary and secondary invaders depend heavily on microclimatic shifts and insect-mediated or physical injuries, field scouting must simultaneously monitor the fungal pathogens progression. Select 20 random plants per acre across the field at boll development stage at weekly interval. Increase the frequency every 3–4 days following continuous rainfall events, prolonged cloudy weather, or unseasonal high-intensity dew periods during

late flowering and early boll bursting.

Economic threshold: 10% bolls infected

Management strategy:

Crop growth stage: 0–60 DAS

- **Genotype selection:** Choose early- to mid-duration varieties to ensure boll opening that escapes late-season monsoon rains.
- **Seed treatment:** Treat seeds with *Trichoderma viride/harzianum* @ 10 g/kg seed or systemic fungicides such as Carboxin 37.5% + Thiram 37.5% DS @3.5 g/kg seeds to eliminate seed-borne inoculum. Apply *Trichoderma* formulations enriched in farmyard manure to the soil during early inter-cultivation.
- **Optimum sowing:** Adjust sowing dates so that peak boll maturity and opening phases do not coincide with predictable periods of heavy, continuous rainfall.
- **Plant spacing:** Maintain plant spacing as per soil type and genotype recommended for the particular cotton growing zone.
- **Fertilizer and drainage:** Ensure proper field drainage to prevent waterlogging. Apply balanced chemical fertilizers, strictly avoiding the overuse of nitrogen and phosphorus, which causes rank vegetative overgrowth.

Crop growth stage: 61–90 DAS

- **Canopy management:** If vegetative growth is high, manage the canopy with the plant growth regulator like Mepiquat Chloride to restrict growth, shorten internodes, reduce canopy humidity, and minimize leaf wetness.
- **Sucking pest management:** Sucking insects puncture young green bolls, creating external wounds that serve as immediate entry points for opportunistic molds and fungal pathogens. Mange these pests as per recommended strategy.
- **Prophylactic sprays:** Prophylactic foliar sprays during flowering and boll development stages (60–120 DAS) on the basis of congenial weather conditions. Recommended fungicides sprays includes application of Carbendazim 50% WP@4 g followed by or Propiconazole 25% EC @ 10 mL or Azoxystrobin 18.2% w/w + Difenoconazole 11.4% w/w SC @ 10 mL or Fluxapyroxad 167 g/L + Pyraclostrobin 333 g/L SC @ 6 ml per 10 litres of water.

Crop growth stage: 91–120 DAS

- **Curative sprays:** Depending on disease severity and weather conditions, a second spray may be given at the interval of 15 days.
- **Spray coverage:** When applying protective fungicides, ensure spray nozzles are directed into the middle and lower thirds of the canopy. Fungicides may be ineffective against fungal boll rot if they only coat the top leaves; thorough, direct coverage of the bolls is mandatory.

Crop growth stage: >120 DAS

- **Defoliation:** If available,apply defoliants to maximize aeration and sunlight around

mature bolls. Execute clean, quick pickings to avoid exposing open bolls to late-season dampness.

- **Picking:** Picking may be carried out at 60 % boll opening.
- ***In-situ* pathogen inoculum management:** Treat the shredded material with *Trichoderma harzianum* or *T. viride* @ 5 g/L and incorporate it back into the soil to promote rapid decomposition and reduce pathogens inoculum.

5. TARGET SPOT

National importance: Target spot disease has emerged as one of the major foliar diseases of cotton in India, with an increasing incidence across all major cotton-growing states. Driven by changing climatic patterns, specifically prolonged rainfall, high humidity, and moderate temperature, this disease poses a significant threat to sustainable cotton production and profitability of farmers (Salunkhe et al., 2019; Prasad et al., 2022; Sain et al., 2026).

Causal Organism: *Corynespora cassiicola* (Berk. & Curt.) C.T. Wei

Economic impact: Target spot disease significantly reduces cotton productivity by causing premature defoliation, decreased photosynthetic efficiency, boll shedding, reduced boll size, and poor fibre quality. Yield losses generally range from 10-30%, although severe epidemics under favourable environmental conditions may result in losses exceeding 50%. In addition to direct yield reduction, the disease increases production costs due to repeated fungicide applications and other disease management practices (Prasad et al., 2025a)

Disease symptoms: The disease symptoms initially appear as small, circular, brown lesions on mature leaves, which gradually enlarge and develop characteristic concentric thin rings, giving a target-like appearance. As lesions coalesce, large necrotic patches are formed, leading to blighting and premature leaf drop. Under severe infection, lesions may also develop on petioles, stems, and bolls, resulting in boll rot, reduced boll opening, and poor fibre development (Prasad et al., 2025b; Sain et al., 2026).

Small size Target spot on leaves

Large size Target spot on leaves

Seasonal disease incidence: Target spot generally appears 60–70 days after sowing and reaches maximum severity during the flowering and boll development stages. Disease incidence is highest during the months of August to October when temperatures ranges

between 25 and 30°C, relative humidity exceeds 85%, and prolonged leaf wetness persists due to frequent rainfall and cloudy weather.

Disease cycle and epidemiology: The pathogen is a necrotrophic and highly polyphagous capable of infecting more than 500 plant species. It survives between cropping seasons in infected crop debris, alternate hosts and occasionally on seed. Under congenial environmental conditions, conidia formed on infected tissues which then disseminated by wind and rain splash, produces primary infections. The fungus carries repeated cycles of sporulation and infection throughout the cropping season, making target spot a polycyclic disease. Warm temperatures, prolonged leaf wetness, high humidity, dense crop canopy, excessive nitrogen fertilization and irrigation favour fast disease development and outbreaks (Sain et al., 2026).

Disease surveillance: Regular field monitoring and surveillance is important for the early detection and effective management of target spot. Fields should be monitored from 45 days after sowing at 7–10 days interval, particularly during high humidity and rainfall conditions. Disease surveillance involves systematic field scouting, recording disease incidence and severity, monitoring climatic conditions and identifying susceptible hybrids. Calculate the disease incidence percentage by dividing the number of infected plants by the total number of plants observed and multiplying by 100. To assess actual damage, calculate the Per Cent Disease Index (PDI) using a standard 0–4 disease rating scalebased on leaf area infection.

Economic threshold: Although a universally accepted economic threshold for target spot in cotton has not been established however, management should start when approximately 10–15% of cotton plants show typical lesions or when 5–10% foliage area is affected during the flowering to boll development stages under suitable environmental conditions.

Management strategy

Pre-sowing

- **Inoculum reduction:** Deep summer ploughing would expose soil-borne pathogens to solar radiation. Promptly remove and destroy infected crop residues from preceding seasons to eliminate primary infection sources.
- **Canopy management:** Follow recommended plant spacing to optimize proper aeration within the crop canopy and reduce humidity levels.
- **Select resistant cultivars:** Select resistant cultivars/hybrids.
- **Cultural control:** Follow crop rotation with non-host species to disrupt the disease cycle.
- **Fertilizer and water management:** Optimize fertilizer inputs by avoiding excessive nitrogen and phosphorus application. Prevent over-irrigation and delayed sowing to minimize conditions conducive to pathogen proliferation.

Crop growth stage: 61–90 DAS

- **Disease surveillance:** Inspect the crop at weekly intervals, particularly the lower canopy, for the appearance of circular brown lesions with characteristic concentric target-like rings.
- **Canopy management:** Apply Mepiquat Chloride 5% AS @ 1–1.2 mL/L to regulate

canopy density, improve air circulation, and reduce humidity and leaf wetness within the crop canopy.

- **Fungicidal protection:** On the appearance of disease symptoms, spray Carbendazim 50 WP @ 2 g or Propiconazole 25 EC @ 10 mL or Pyraclostrobin 5% + Metiram 55% WG @ 20 g or Propineb 70 WP @ 25–30 g or Azoxystrobin 18.2% + Difenoconazole 11.4% SC @ 10 mL or Fluxapyroxad 167 g/L + Pyraclostrobin 333 g/L SC @ 6 mL/10 L of water.

Crop growth stage: 91–120 DAS

- **Chemical management:** During prolonged rainy periods or under severe disease pressure, apply fungicides mixture with systemic and translaminar activity, such as Fluxapyroxad + Pyraclostrobin (@ 0.6 mL/L of water) or Azoxystrobin + Difenoconazole (@ 1.0 mL/L of water). Ensure thorough spray coverage of the lower and middle canopy where infection is most prevalent to achieve effective disease suppression.

Crop growth stage: >120 DAS

- ***In-situ* inoculum reduction:** After harvest, shred the crop residues by using shredder machine and apply *Trichoderma harzianum* or *Trichoderma viride* @ 5 g/L of water before incorporating chopped shredded residues into the soil. This helps fast decomposition of residue, suppresses the survival of the pathogen lead to lowers the inoculum load for the subsequent cropping season.

6. ALTERNARIA LEAF SPOT

National importance: The disease has spread across all the three cotton growing zones of India. Weather conditions characterized by high humidity and fluctuating rainfall patterns during vegetative and early boll-stage attacks, causing square drop and smaller boll sizes.

Causal organism: *Alternaria macrospora*, *A. alternata* and *A. gossypina*

Economic impact: Widespread premature defoliation starves developing bolls of vital photosynthates. This induces forced, premature boll opening, resulting in immature fibers with poor micronaire values that fetch low market prices. Fibers from infected plants exhibit reduced staple length and lower tensile strength, which increases lint breakage during high-speed industrial spinning. When foliar infestations progress onto the carpel walls, the dark fungal spores permanently stain the lint, rendering it unsuitable for premium or export-grade combed yarn manufacturing. Depending on cultivar susceptibility and the timing of disease onset, independent seed cotton yield losses range from 10 – 30%.

Disease symptoms: Initial disease symptoms present as small (0.5–2.5 mm), circular, brown lesions with distinct purple margins. Symptoms vary by pathogen species: *A. macrospora* being a major pathogen causes brown to grayish-brown or tan-colored lesions measuring 3–10 mm in diameter on the lower leaves. Later, these lesions expand, forming concentric rings with cracked centers. In contrast, *A. alternata* induces purple lesions with prominent purple margins; severe infection leads to foliage desiccation and eventual defoliation. *A. gossypina* causes chlorosis and drying of the leaves, as well as premature

defoliation and boll rot. Association of both *A. macrospora* and *A. alternata* is usually found leading to blight of cotton. Under favourable weather conditions, these pathogens cause extensive necrotic spotting, rapid defoliation, and abundant sporulation on abscissed leaves. The disease is notably more severe on older, lower leaves, and cotton plants bearing a heavy boll load exhibit significantly higher susceptibility.

Seasonal disease incidence: The disease occurs during vegetative growth to boll development / maturity stage (20–150 DAS). The disease incidence remains generally low up to 45DAS, moderate during squaring, peak flowering, and early boll formation stage, while maximum severity during boll development to maturity and opening.

Disease cycle and epidemiology: Disease is a polycyclic disease and completes several cycles of infection under favourable weather conditions. Infected crop debris or seed serves as the primary source of inoculum where spores survive the adverse climatic conditions. Optimum temperature for sporulation is 25–30°C and sporulation is higher on older leaves than on younger leaves. The pathogen requires longer leaf wetness period to infect at optimum temperature range of 20–30°C and can sporulate up to 35°C. Frequent rainfall with high relative humidity of 65–90% and temperature range of 20–28°C is highly conducive for disease development.

Alternaria spot on green leaf

Alternaria spot on older leaf

Advanced Alternaria leaf spot symptoms

Alternaria leaf spot coupled with Cotton jassid infestation

Disease surveillance: Scout the field along 'X' or 'Z' pattern, randomly sampling at least 20 plants per acre. Monitor the crop fortnightly during the vegetative stage (0–45 DAS) and weekly from squaring to peak flowering (45–90 DAS). During boll development and maturity (>90 DAS), inspect the field every 3 to 4 days if cloudy, humid weather or unseasonal rains occur. Calculate the disease incidence percentage by dividing the number of infected plants by the total number of plants observed and multiplying by 100. To assess actual damage, calculate the Per Cent Disease Index (PDI) using a standard evaluation scale, typically ranging from 0–4 based on leaf area infection.

Economic threshold: 2% to 5% disease incidence.

Management strategy:

Pre-sowing

- **Field sanitation:** Collect and destroy infected crop residues from the previous season to minimize overwintering fungal propagules.
- **Deep summer ploughing:** Turn the soil during the summer months to expose resting fungal structures to intense solar heat, reducing primary soil-borne inoculum.
- **Cultivar selection:** Prefer resistant / tolerant varieties/hybrids. Choose early to mid-duration varieties to ensure that peak maturity avoids late-season monsoon dampness.
- **Sowing time:** Optimize sowing dates so that peak boll development and opening do not coincide with predictable periods of continuous late-season rainfall or excessive dew.

Crop growth stage: 0–60 DAS

- **Seed treatment:** Treat acid-delinted seeds with Carbendazim 50% WP @ 1 g/kg seed or Carboxin 37.5% + Thiram 37.5% DS @ 3.5 g/kg seed. Alternatively, apply *Trichoderma viride* or *T. harzianum* formulations @ 10 g/kg seed to protect emerging seedlings.
- **Spacing:** Adhere spacing according to soil type and genotype recommended to the zone.
- **Weed management:** Keep fields and borders free of malvaceous weeds and collateral hosts that act as early-season multiplying zones for *Alternaria* spores.
- **Fertilizer management:** Apply a balanced basal dose of fertilizers based on soil tests. Ensure the full recommended basal dose of Muriate of Potash is applied, and avoid excessive early nitrogenous fertilizer applications that trigger lush, dense, susceptible vegetative growth.

Crop growth stage: 61–90 DAS

- **Monitoring:** Scout the lower canopy weekly. Monitor the field closely for expanding brown lesions with target-board concentric rings.
- **Fertilizer management**: Apply a foliar spray of 1–2% Potassium Nitrate (13:0:45)

at fortnightly intervals. This directly supplements the leaves, preventing stress-induced premature senescence and strengthening cell walls against fungal entry.

- **Canopy management:** If the canopy becomes overly dense or rank, apply the plant growth regulator Mepiquat Chloride 5% AS @ 1.0–1.2 mL /L to improve airflow, lower canopy humidity, and reduce leaf wetness duration.
- **Fungicide spray:** If the field Percent Disease Index (PDI) reaches 5% to 10%, immediately apply a protective foliar spray of Propiconazole 25% EC @ 1.0 mL/L or Azoxystrobin 18.2% + Difenoconazole 11.4% w/w SC @ 1 mL/L of water.

Crop growth stage: 91–120 DAS

- **Chemical spray:** Under high disease pressure or persistent rainfall, deploy advanced combination fungicides that offer both systemic and translaminar action for longer residual protection such as Fluxapyroxad 167g/7 + Pyraclostrobin 333 g/L SC @ 0.6 ml/L of water or Azoxystrobin 18.2% + Difenoconazole 11.4% w/w SC @ 1.0 mL/L of water. Ensure that fungicide applications are directed deep into the lower and middle thirds of the canopy. Direct contact with the infected leaf zones is mandatory for effective control.

Crop growth stage: >120 DAS

- **Timely defoliation:** Apply recommended chemical defoliants when 60–70% of bolls are open.
- **Harvesting:** Execute prompt and clean pickings of opened bolls. Minimize the crop duration so that lint should not exposed to unseasonal late rains or heavy morning dew to prevent opportunistic *Alternaria* spores from staining and degrading the fibers.
- ***In-situ* pathogen inoculum management:** Treat the shredded material with *Trichoderma harzianum* or *T. viride* @ 5 g/L and incorporate it back into the soil to promote rapid decomposition and reduce pathogens inoculum.

7. MYROTHECIUM LEAF SPOT

National importance: Historically classified as a minor foliar disease of cotton in India, *Myrothecium* leaf spot (also referred as Myrothecium Leaf Blight), has gained significant national and economic importance over the last two decades. Driven by shifting weather patterns, changing agronomic practices, and the widespread adoption of *G. hirsutum* genotypes, it has transitioned into an emerging destructive threat across major cotton-growing zones of India.

Causal organism: *Paramyrothecium roridum* (Synonym=*Myrothecium roridum*)

Economic impact: In highly susceptible genotypes, severe outbreaks are documented to cause 15–20% losses in seed cotton yield, with some regional estimates tracking production drops up to 30% under peak disease pressure.

Disease symptoms: *Myrothecium* leaf spot causes severe leaf spot and blight in cotton,

appearing as circular or irregular, 2–10 mm spots with light brown centers and purple margins. Initially, minute water-soaked, dark purple spots or streaks appear on leaves, which merge into large, necrotic, light brown, or gray patches. Infection is characterized by gray-centered, dark-margined necrotic spots, often starting from leaf margins, leading to premature defoliation. It can also affect seedlings, causing stem and petiole necrosis. In high humidity, raised black spore masses with white tufts form on the lesions. Later, center of old lesions may fall out, creating a "shot hole" appearance. Cotton plants with high boll load are more susceptible and it can cause infection on bolls too.

Leaf spot on leaf

Blight symptoms on leaf

Leaf spot on plant

Severely infected leaf

Seasonal disease incidence: The disease start appearing from seedling to early vegetative stage (30–45 DAS), progressed during peak vegetative growth to early flowering/squaring while peak incidence can be seen during boll development and maturation stage (late August to late October) in North, Central and South India.

Disease cycle and epidemiology: The fungus survives the off-season as spores (conidia) or mycelium on infected plant debris left in the field, or occasionally on seeds. During the rainy season, spores are spread to healthy cotton leaves primarily by rain splashes, irrigation and wind. In the presence of a film of water on the leaf and high humidity, the spores germinate and penetrate the leaf tissue. Within lesions on leaves, the fungus produces black, cushion-like fruiting bodies and spores are spread by wind and water to the upper canopy and healthy

plants, during humid periods. Later on, the necrotic centers may dry out and drop to the soil, where the fungus returns to its survival phase in the debris.

Disease surveillance: Begin weekly scouting from 30 DAS. Walk the field in an 'X' or 'Z' pattern, inspecting at least 20 plants per acre. Focus first on the oldest, lower-tier leaves, as early seasonal symptoms develop here due to soil-splash dispersal and proximity to overwintering crop residue. In dense-canopy Bt cotton hybrids, inspect the middle canopy as well. Look for circular to irregular tan or grayish-brown spots (2 mm to >10 mm wide) with distinct concentric rings. Check if the brittle centers of older lesions have crumbled away to form characteristic 'shot-holes'.Calculate the disease incidence percentage by dividing the number of infected plants by the total number of plants observed and multiplying by 100. To assess actual damage, calculate the Per Cent Disease Index (PDI) using a standard evaluation scale, typically ranging from 0–4 based on leaf area infection.

Economic threshold: 1–5% disease incidence.

Management strategy:

Crop growth stage: 0–60 DAS

- **Seed treatment:** Ensure seeds are treated before sowing with Carbendazim 50% WP @ 1 g/kg seed or a biological agent like *Trichoderma viride* or *Pseudomonas fluorescens* @ 10 g/kg seed to minimize early systemic or contact stress.
- **Field sanitation & sowing:** Maintain field sanitation by removing stubble from the previous season to deplete over-wintering conidia. Avoid overcrowding by following recommended spacing as per soil type and genotype.
- **Balanced fertilizer:** Apply a basal dose of fertilizer. Avoid excessive early-stage nitrogenous fertilizers, which induce soft, succulent vegetative tissues that are highly susceptible to early fungal penetration.
- **Scouting:** Begin weekly or bi-weekly scouting from 30 DAS, focusing entirely on the lower-tier leaves for small water-soaked or tan spots.

Crop growth stage: 61–90 DAS

- **Biological control:** Spray bio-agents like *Pseudomonas fluorescens* @ 10 g/L under moderately humid, non-rainy conditions to compete with the pathogen on leaf surfaces.
- **Chemical control:** Spray prophylactic spray of Propineb 70 WP @ 25–30 g or Azoxystrobin 18.2% w/w + Difenoconazole 11.4% w/w SC@ 10 mL or Fluxapyroxad 167 g/L + Pyraclostrobin 333 g/L SC@ 6 g or Carbendazim 50% WP @ 6 g or Pyraclostrobin 5% + Metiram 55% WG @ 20 g /10 L water.

Crop growth stage: 91–120 DAS

- **Chemical control:** If PDI crosses 5% to 10% (Grade 2 to Grade 3) and warm and humid weather persists, spray Propiconazole 25% EC @ 10 mL or Propineb 70 WP @ 25-30 g or Azoxystrobin 18.2% w/w + Difenoconazole 11.4% w/w SC@ 10 mL or Fluxapyroxad 167 g/L + Pyraclostrobin333 g/L SC @ 6 g or Carbendazim 50% WP @ 6 g or Pyraclostrobin 5% + Metiram 55% WG @ 20 g/10 L water.

Crop growth stage: >120 DAS

- **Chemical control:** If late-season rains or heavy morning dews spark a late flare-up on upper leaves, spray Propiconazole 25% EC @ 10 mL or Propineb 70 WP@ 25–30 g or Azoxystrobin 18.2%w/w + Difenoconazole 11.4% w/w SC@ 10 mL or Fluxapyroxad 167 g/L + Pyraclostrobin 333 g/L SC@ 6g or Carbendazim 50% WP@ 6 g or Pyraclostrobin 5% + Metiram 55% WG @ 20 g/10 L water.
- ***In-situ* pathogen inoculum management:** Treat the shredded material with *Trichoderma harzianum* or *T. viride* @ 5 g/L and incorporate it back into the soil to promote rapid decomposition and reduce pathogens inoculum.

8. COTTON RUST

National importance: The disease typically manifests during the dry season (December to March). Although cotton rust generally occurs sporadically, it becomes an economically significant threat due to its early onset in Karnataka and Andhra Pradesh, leading to substantial losses in seed cotton yield. In the North and Central zone, rust is of a minor importance, occurs in late-season that causes little to no economic loss.

Causal organism: *Phakopsora gossypii* (Arth.) Hirats.

Economic impact: Under standard sporadic conditions, yield losses are negligible (less than 5%). However, during early-onset epidemics or in localized pockets with high alternate host pressure, seed cotton yield losses can range from 15–50%.

Disease symptoms: The pathogen initially infects the older leaves located in the lower canopy and subsequently spreads to the younger leaves as the disease progresses. The disease appears as small pinkish-brown uredial sori on leaves and is favoured by warm temperatures and high humidity. The uredial sori develop on the leaves as small, pinkish-brown spots measuring about 1–3 mm in diameter, which may later coalesce to form larger necrotic patches under severe infection. The uredia are typically oval to circular in shape and are borne on pedicels and branches, contributing to further spread of the disease on the foliage.

Cotton rust on adaxial surface

Cotton rust on plant

Uredial pustules on under surface of leaf

Cotton rust on boll

Seasonal disease incidence: The disease is generally observed in the dry season during early November-March in Southern India (120–160 DAS).

Disease cycle and epidemiology: During the off-season, the fungus survives on wild grasses or volunteer cotton plants, near field borders, irrigation channels, and wastelands. Uredospores spread rapidly via wind currents and rain splash, allowing localized infections to escalate into field-wide epidemics. Upon landing on the leaf, the spore germinate and directly penetrate the cuticle and epidermis. Within 10–14 days, tiny pale-green lesions emerge on the upper leaf surface and rapidly turn into bright yellow-to-orange pustules. Shortly after, cup-like structures called 'aecia' break through the lower leaf epidermis as raised, rough, bright orange-yellow circular lesions. *Phakopsora gossypii* further drives the epidemic by producing repeating asexual spores (urediospores) for rapid canopy spread during warm, and humid conditions. As the cotton crop senesces, these spores blow back onto adjacent grasses, completing the macrocyclic sequence. The disease progress with the growth of cotton crop. Weather conditions, maximum temperature 31.5°C, minimum temperature 22.0°C, morning relative humidity 87%, evening relative humidity 50% favours the rust disease infection (Valarmathi et al., 2025).

Disease surveillance : In high-risk southern states like Karnataka and Andhra Pradesh, monitoring should begin during the late vegetative phase on weekly intervals if the weather extended overcast days with heavy morning dews. Initially observe the field margins, particularly those adjacent to uncultivated wastelands, irrigation channels, or permanent bunds. After checking field borders, move field in 'X' or 'Z' pattern. Observe at least 20 plants per acre. Calculate the disease incidence percentage by dividing the number of infected plants by the total number of plants observed and multiplying by 100. To assess actual damage, calculate the Per Cent Disease Index (PDI) using a standard evaluation scale, typically ranging from 0–4 based on leaf area infection.

Economic threshold : 5–10% plant infected

Management strategy:

Crop growth stage : 0–60 DAS

- **Field border sanitation**: Eradicate primary inoculum sources along field borders. Mechanically clear, or treat field borders, bunds, irrigation channels, and adjacent wasteland tracts with non-selective herbicides to eliminate wild grama grasses so as to disrupts the primary infection cycle.
- **Fertilizer management:** Avoid excessive nitrogenous fertilizers, which promote lush, succulent leaf tissue that is easily penetrated by rust germ tubes. Ensure adequate Potassium application to strengthen cell wall resilience against direct fungal puncture.
- **Spacing and canopy management:** Crop sown at proper/wider spacing and maintaining proper canopy aeration help in minimizing the disease incidence and severity.

Crop growth stage: 61–90 DAS

- **Chemical control:** If scouting reveals initial under-leaf yellow-to-orange aecia or uredinia in traces (disease severity less than 1–2%), apply foliar spray of Carbendazim 12% + Mancozeb 63 % WP @ 30g/10L of water.

Crop growth stage: 91–120 DAS

- **Chemical control:** If scouting reveals initial under-leaf yellow-to-orange aecia or uredia in traces (Disease Severity less than 1–2%), apply foliar spray of Fluxapyroxad 167 g/L + Pyraclostrobin 333g/L SC @ 10g or Azoxystrobin 18.2% + Difenoconazole 11.4% w/w SC @ 10 mL or Metiram 55% + Pyraclostrobin 5% WG @ 20 g or Carbendazim 12% + Mancozeb 63% WP @ 30g/10 L of water.

Crop growth stage: >120 DAS

- **Canopy protection:** If unseasonal late rains or heavy morning dews trigger a rust on the upper canopy, spray Fluxapyroxad 167 g/L + Pyraclostrobin 333g/l SC @ 10g or Azoxystrobin 18.2% + Difenoconazole 11.4% w/w SC @ 10 ml or Metiram 55% + Pyraclostrobin 5% WG @ 20 g or Carbendazim 12% + Mancozeb 63 % WP @ 30g /10L of water**.**
- **Post-harvest management:** Once the final picking is complete, do not leave infected cotton stalks or crop debris standing in the field. Deeply plough or shred these crop residues to expose dropped leaf litter to soil microbial degradation. Additionally, clear any surrounding wild grasses that are beginning to dry; they harbour the hardy teliospores that will otherwise sourced primary infections during the next crop cycle.

9. GREY MILDEW

National importance: The disease has evolved from a minor, sporadic occurrence into a major national concern across India's cotton-growing regions. Because many popular

commercial Bt hybrids lack genetic resistance to grey mildew, the fungus establishes rapidly under favorable conditions. The disease occurs nationwide; however, the Central and South zones particularly rainfed ecosystems experience severe outbreaks during years with high humidity and extended late-season monsoons, whereas the Northern zone remains less susceptible.

Causal organism: *Ramularia areola* Atk. (=*R. gossypii*) (conidial stage/anamorph), *Mycosphaerella areola* Ehrilch and Wolf (perfect stage/teleomorph).

Economic impact: The disease has showed an increasing trend from 2008–2011 with PDI ranged from 11.5–32.2%. A potential yield loss is estimated to be 25.6–46.6% in South India.

Disease symptoms: The disease is characterized by irregular, angular, pale, translucent spots measuring 1–10 mm in size surrounded by veinlets. The disease usually appears on the older leaves when the plants are reaching maturity. The disease is known by different names like false mildew, areolate mildew, grey mildew, brown leaf spot, frosty blight, white mold, etc. In Maharashtra, the grey mildew is commonly referred to as *'Dhaiya'* or *'Dahya'* disease because of the symptoms resembling sprinkled curd on foliage. A frosty or mildew growth consisting of conidiophores and conidia of the fungus appear first on the under surface of older leaves and subsequently on the upper surface of affected leaves.

Seasonal disease incidence: During the vegetative stage, the pathogen remains dormant as ascospores or within plant debris. At the flowering and fruiting stage, the first symptoms appear on mature, older leaves in the lower canopy as small (3–4 mm), angular, pale-green, translucent spots on the lower leaf surfaces. During peak flowering and boll development, the disease moves upward from the lower leaves into the middle canopy. The fungus produces a characteristic whitish-grey, powdery growth resembling sprinkled curd (*Dahiya*). Finally, at boll maturity and opening, severe epidemics reach the upper canopy, bracts, and bolls, causing leaves to cup inward, turn yellowish-brown, and drop prematurely.

Disease cycle and epidemiology: The conidia are hyaline, thin-walled, straight, fusiform, and pointed at both ends, containing one to three septa and arranged either singly, branched, or in short chains. The grey mildew fungus, *Ramularia areola*, progresses through three distinct stages during its life cycle: the conidial, spermogonial, and perithecial stages. Ascospores serve as the primary source of inoculum for the disease. Subsequently, the fungus develops further, producing conidia on green leaves that drive secondary spread throughout the crop season. Because grey mildew is a polycyclic disease, prolonged favorable weather characterized by extended spells of high moisture, humidity, and optimum temperatures can trigger severe epidemics resulting in complete defoliation and catastrophic crop loss. Specifically, heavy rainfall from June to September, combined with a temperature range of 23–29°C and a relative humidity of 78–85% in the morning and 45–60% in the evening, creates highly conducive conditions for rapid disease development and spread.

Grey mildew on lower surface of leaf

Severely infected plant foliage

Initial water soaked leaf spots

Mildew spots on square

Disease surveillance: Walk the field in a zigzag or 'X' or 'Z' pattern, avoiding field borders or rows immediately adjacent to trees and irrigation channels, as these areas present unrepresentative humidity levels. Examine approximately 20 plants per acre, focusing closely on the lower third of the canopy first. Look specifically at mature, older leaves where air circulation is restricted. Initial lesions present as small (3–4 mm), angular, pale-green, translucent spots delimited by leaf veins, followed shortly by a characteristic white-to-grey powdery growth on the lower surface. Calculate the disease incidence percentage by dividing the number of infected plants by the total number of plants observed and multiplying by 100. To assess actual damage, calculate the Per Cent Disease Index (PDI) using a standard evaluation scale, typically ranging from 0–4 based on leaf area infection.

Economic threshold: 5–10% disease incidence in the lower canopy during the flowering/ fruiting phase.

Management strategy:

Crop growth stage: 0–60 DAS

- **Field sanitation:** Deep summer ploughing prior to sowing to bury infected crop residues from the previous season. Maintain fields free of weeds and volunteer cotton plants that might harbour early inoculum.

- **Fertilizer management:** Avoid excessive nitrogenous fertilizers, which induce luxurious vegetative growth. Balance fertilizer applications based on soil health cards is advocated.

Crop growth stage: 61–90 DAS

- **Biocontrol:** Foliar spray of *Pseudomonas fluorescens* or *Bacillus subtilis* @ 5–10 g/L can be applied under low pressure.
- **Chemical spray:** If initial lesions are observed on lower leaves (crossing 5–10% disease incidence), initiate a spray of Carbendazim 50% WP @ 1 g/L or Pyraclostrobin 20% WG @ 2 g/L or Azoxystrobin 18.2% + Difenoconazole 11.4% SC @ 1 ml/L or Metiram 55% + Pyraclostrobin 5% WG @ 2 g/L or Kresoxim-methyl 44.3% SC @ 1 mL/L of water.

Crop growth stage: 91–120 DAS

- **Biocontrol:** Apply foliar spray of *Trichoderma harzianum* @ 50 g/10 L of water.
- **Chemical spray:** If microclimatic conditions remain highly favourable such as intermittent late-season rains, heavy morning dew and the disease is climbing into the mid-canopy, spray any of the fungicide such as Azoxystrobin 18.2% + Difenoconazole 11.4% SC @ 1 mL/L or Pyraclostrobin 20% WG @ 1 g/L or Kresoxim-methyl 44.3% SC @ 1 mL/L or Propineb 70% WP @ 1 g/L.

Crop growth stage: >120 DAS

- **Avoid chemical spray:** Avoid chemical sprays if the crop is already moving towards natural senescence and a significant portion of bolls have safely opened.
- **Post-harvest residue management:** Immediately after final picking, do not leave crop residues in the field. Uproot stalks and safely compost or incorporate debris to break the overwintering survival cycle of the perithecia/ascospores, reducing the primary inoculum load for the next season.

10. BACTERIAL LEAF BLIGHT

National importance: Bacterial leaf blight (BLB), is one of the most destructive diseases affecting cotton in India. Often referred to as Blackarm or Boll Rot depending on the affected plant part. The disease affects all the growth stage of the crop, directly threatening lint yield, seed quality, and fiber properties across all cotton growing zones. BLB is a systemic vascular disease that can cause total crop failure if left unmanaged under epidemic conditions. Multiple virulent races of the bacterium exist across India.

Causal organism: *Xanthomonas citri* pv. *malvacearum* (Synonym = *Xanthomonas axonopodis* pv. *malvacearum*)

Economic impact: In high-humidity conditions with susceptible cultivars, yield losses can range from 20–50%, occasionally causing complete crop failure in localized fields. As the disease is systemic and seed-borne, infected bolls produce smaller, weaker seeds with poor viability. This affect seed germination and oil contents.

Disease symptoms: Small, round, water-soaked spots appear on the cotyledons at seedling stage. As the disease progressed, these spots quickly turn brown or black, drying out the cotyledons. Four phases of the disease viz., seedling phase, angular leaf spot & vein blight phase, black arm phase and boll rot phase are recognized. The disease is very severe during high humid conditions. The infection often spreads down the petiole to the young seedling stem, leading to seedling collapse and death. During the vegetative growth stage lesions start as tiny, water-soaked spots on the lower as well as upper surface of the leaves. As the spots enlarge, their expansion is stopped by the lateral veins of leaves. This gives the lesions a sharp, angular shape rather than a round one. Further disease progression, the spots turn from dark green to brown or deep black. Under humid conditions, a sticky, amber-coloured bacterial ooze exudes from these spots, which dries into a thin, whitish crust. Severe infections cause the leaves to turn yellow, wither, and drop off early (Borkar et al., 1980). The disease manifests on young, green bolls as small, water-soaked, circular spots.

Leaf infected with BLB

BLB nectoric leaf spot

Water-soaked leasion on the boll

Leaf spot and vein blight symptoms

Seasonal disease incidence: Cotton plants are highly vulnerable to BLB at seedling stage causing cotyledonary blight and at the squaring to boll-formation stage leading to boll rot and lint staining. In Central and South zones frequent spells of high humidity (>85) combined with ambient temperatures ranging between 25°C and 35°C trigger rapid fieldwide spread. While in north zone, early monsoon rains coinciding with high summer temperatures can lead to severe seedling and vegetative outbreaks.

Disease cycle and epidemiology: The bacterium overwinters in infected seed, cotton stalks, leaves, and unharvested bolls left standing or shallowly buried in the field (Sain et al., 2023). The bacterium spreads through rain splash, irrigation water, and farm operations. When infected seeds germinate, the bacteria wake up and attack the emerging plant, infect the cotyledons, causing water-soaked, round lesions. This is the primary mode for introducing the disease to new fields. Warm humid conditions favour disease development (Verma and Singh, 1971). The pathogen enters the plant tissues through natural openings like stomata or hydathodes, as well as through mechanical wounds caused by wind, hail, or cultivation tools. Under warm, humid conditions, infected leaves exude a sticky, amber-colored bacterial ooze packed with billions of active cells. Windy rain, overhead splash irrigation, and field labourers brushing against wet plants carry this ooze from infected plants to healthy plants. The transition from a few scattered leaf spots to a full-blown blackarm or boll rot epidemic relies entirely on the susceptible host, a virulent pathogen race, and specific atmospheric conditions.

Disease surveillance: Walk the field in 'X' or 'Z' pattern. Scout once a week starting from seedling emergence. Increase this to twice a week during continuous monsoon rains, high humidity or heavy winds. Examine 20 randomly selected plants per acre. During early to mid-season examine lower leaf canopy. The first signs of angular leaf spot appear on the underside of lower leaves as tiny, water-soaked area. Look closely for a shiny, dried film on the underside of the leaf lesions. This is dried bacterial ooze and is the definitive field indicator of BLB. During mid-season look for dark brown or black streaks on petioles and fruiting branches. If a branch is wilting despite wet soil, check the base of that branch for a black, girdling lesion. At boll developing stage examine green bolls for round, water-soaked, sunken lesions. Inspect bolls located in the dense lower third of the plant canopy where dew and humidity linger the longest. A disease rating scale of 0-4 can be used to access disease severity. Calculate disease incidence (%) by counting number of plants showing BLB symptoms by total number of plants scouted and multiplied by 100.

Economic threshold: 2–5% plants showing progressive BLB symptoms.

Management strategy:

Pre-sowing

- **Acid delinting:** Ensure seeds are delinted using sulfuric acid. This destroys external bacterial inoculum harbored on the fuzzy seeds.
- **Seed treatment:** Treat delinted seed with Carboxin 37.5% + Thiram 37.5% WS @ 3.5 g/kg seed or *Pseudomonas fluorescens* @ 10g/kg seed.
- **Resistant varieties:** Select approved, disease resistant Bt cotton hybrids suitable for specific zone.

Crop growth stage: 0–60 DAS)

- **Field scouting:** Walk your field in 'X' or 'Z' pattern weekly. Closely check the lower cotyledonary leaves for small, water-soaked angular spots.
- **Roguing:** Remove and destroy early infected seedlings to prevent the build-up of initial inoculum pockets.

- **Chemical spray:** If early foliar symptoms emerge and the weather is highly humid, spray Carbendazim 12% + Mancozeb 63 % WP @ 30g /10L of water.

Crop growth stage: 61–90 DAS

- **Balanced fertilizer:** Avoid excessive applications of nitrogenous fertilizers. Excess nitrogen creates a highly succulent, dense canopy that traps micro-humidity and weakens cell walls, inviting rapid bacterial entry. Apply balanced potassium to boost natural plant immunity.
- **Weed control:** Keep fields clean by removing alternate hosts and weeds. Dense weed growth blocks airflow, creating a stagnant, high-humidity microclimate ideal for the bacteria.
- **Chemical spray:** If disease incidence crosses 5–10%, apply a spray of Carbendazim 12% + Mancozeb 63 % WP @ 30g /10L of water and repeat at fortnight intervals if heavy monsoon showers and high wind velocity persist.

Crop growth stage: 91–120 DAS

- **Water management:** Avoid overhead sprinkler irrigation if BLB is present rather prefer furrow irrigation.
- **Boll inspection:** Closely evaluate the round, water-soaked lesions on young green bolls in the lower, dense tier of the plant.
- **Chemical protection:** Spray or Carbendazim 12% + Mancozeb 63 % WP @ 30g /10L of water.

Crop growth stage: >120 DAS

- **Clean picking:** Harvest early-bursting clean bolls separately from late, partially rotted, or stained bolls.
- **Crop residue management:** Do not let infected cotton residue in the field beyond season. The bacteria overwinter successfully on dry stalks, leaves, and stained locules.
- **Deep ploughing:** Collect and destroy heavily infected crop residues or execute deep summer ploughing using a moldboard plough.

11. COTTON LEAF CURL DISEASE

National importance: Cotton Leaf Curl Disease (CLCuD) in India is classified as one of the most economically devastating and high-priority biotic threats to Indian agriculture. Widespread outbreaks of CLCuD pose a direct risk to national economic stability. CLCuD is a major limiting factor primarily focused in the North cotton growing zone (Punjab, Haryana, and Rajasthan). This zone manages over 1.5 million hectares of cotton.

Causal organism: The CLCuD is caused by virus under the genus *Begomovirus*, a monopartite virus with circular ssDNA as its genome. CLCuD virus is often associated with beta satellite (circular ssDNA) and alpha satellites (ssDNA). CLCuD is transmitted by

whitefly (*Bemisia tabaci*). It is one of the most serious virus diseases caused by Gemini virus.

Economic impact: Historically, major epidemics in the subcontinent have caused losses estimated between $630 million to $670 million in a single production cycle. Depending on the susceptibility of the hybrid and how early the whitefly vector (*Bemisia tabaci*) inoculates the crop, individual field yield losses range from 15–80%. The virus disrupts the plant's vascular physiology, altering the cellular composition of cellulose, wax, and pectin. This degrades critical fiber properties including staple length, bundle strength, micronaire, and the uniformity index

Disease symptoms: The initial symptoms of the CLCuD are characterized by small vein thickenings on upper young leaves. Leaves show distinct upward and or downward curling along with increase in vein thickenings. Sometime infected leaves form secondary, leaf-like structures known as enation that emerge from the nectaries point. Reduced internodal length and plant stunting occur in severe infection along with considerable reduction in flowering, square formation and boll formation. Severely affected plants due to infection at early stage are stunted and such plants often do not bear any fruiting bodies. Disease severity depends on its time of incidence level of resistance/ susceptibility of individual genotypes as well as the vector population. A 0–6 disease rating scale is used to record its disease severity.

Vein thickening darkening symptoms

Downward leaf curling

Upward leaf curling

Leaf enation symptoms

Seasonal disease incidence: Timely sown crops (15 April to 15 May) remain escaped from early CLCuD infection.Timely sowing allows the crop to establish a robust structural canopy and develop tough, mature leaves well before vector populations peak. Conversely, late sowing after May 15th forces tender, succulent seedlings to emerge during transitioning weather, pre-disposing them to immediate virus inoculations. The situation intensifies from late June to August, the most critical window for CLCuD transmission. During this period, the Southwest monsoon introduces a warm, highly humid microclimate within the leaf canopy, featuring temperatures between 33°C and 40°C and relative humidity above 75%. These ideal conditions trigger an explosion in the whitefly population, which rapidly spreads the Begomovirus complex from nearby weed reservoirs and alternate hosts like vegetable crops, cucurbits, okra into the cotton crop. By August-September, the development of new visual symptoms slows as the crop shifts its energy from vegetative growth to reproductive boll maturation. Although adult whitefly populations may still spike sporadically in mid-to-late September, these late-season infections fail to cause severe stunting because the plant's structural architecture is already fully formed.

Disease cycle and epidemiology: CLCuD is exclusively transmitted by whitefly vector in a persistent circulative manner to cotton plants from infected weeds, alternate malvaceous crop hosts such as vegetables which serve as reservoirs of the virus during the off-season. Whitefly feeds on infected plants and acquires the virus, become viruliferous and later inoculate the virus into healthy plant tissues while feeding. Infected plants/weeds serve as secondary sources of inoculum leading to rapid secondary spread field-level epidemics under favourable conditions. Dry and humid weather, infected weed hosts and viruliferous whitefly population play a significant role in CLCuD out breaks.

Disease surveillance: Monitor the crop weekly starting from 15 DAS up to 120 DAS, increasing the frequency during warm, humid spells. Walk the field in 'X' or 'Z' pattern, selecting 20 plants per acre at random. During the initial phase, look for early visual symptoms such as distinct thickening of small veins on the leaf underside on top leaves accompanied by upward or downward curling of leaf margins. In advanced stages, watch for extreme leaf distortion, puckering, stunting of the main stem internodes, and the appearance of cup-like enations developing directly from the major veins on the lower leaf surface.

Deploy yellow sticky traps at a rate of 8–10 traps per acre, positioned just above the top of the cotton canopy. Check these traps weekly to count adult whitefly catches, providing a clear indication of vector arrival.

Economic threshold: The action threshold for vector management is average 6 adults per leaf or 20 nymphs per leaf.

Management strategy:

Pre-sowing

- **Cultivar selection:** Use certified and recommended resistant / tolerant cotton varieties or Bt cotton hybrids, as the single most effective method to minimize

CLCuD. In known CLCuD hot-spot areas, encourage sowing of *Desi* cotton (*G. arboreum*).

- **Sowing window:** Ensure timely sowing between 15 April and 15 May. Avoid late sowing, as delayed crops are highly prone to severe virus outbreaks.
- **Border rows:** Sow 4–8 border rows of *Desi* cotton around upland cotton fields to act as a physical buffer against incoming whiteflies.
- **Orchard isolation:** Avoid growing upland cotton near citrus orchards or other perennial hosts of the whitefly vector.

Crop growth stage: 0–60 DAS

- **Early rogueing:** Regularly check the field. Remove infected plants at an early stage and bury them deep in pits to stop the virus from spreading to healthy plants.
- **Weed management:** Field sanitation plays an important in CLCuD management. Weeds serve as alternate hosts for both the whitefly vector and the virus. Continuously remove weeds within and around the field margins, bunds and nearby canal areas.
- **Avoid intercropping:** Do not grow okra, cucurbits or tomatoes in or around the cotton field, as they are highly susceptible to whiteflies, alternate can cause a population explosion.
- **Mass trapping:** Install yellow sticky traps (8–10 nos/acer) across the field for early whitefly detection and mass trapping.
- **Early spraying:** Start vector control using eco-friendly neem-based insecticides.
- **Whitefly management:** Control adult whitefly populations using targeted chemistries like Flonicamid, Diafenthiuron, or Dinotefuran. To manage whitefly nymphs deploy insect growth regulators like Pyriproxyfen or Spiromesifen.
- **Avoid synthetic pyrethroids:** Strictly avoid synthetic pyrethroids (such as Cypermethrin, Fenvalerate, Deltamethrin, and Fipronil).

Crop growth stage: 61–90 DAS

- **Balanced nitrogen**: Apply the optimum recommended dose of nitrogen fertilizer at the appropriate split timings. Avoid excess nitrogen, as it causes succulent growth that accelerates whitefly infestation and virus expression.
- **Vector and disease management:** Continue monitoring yellow sticky traps to gauge whitefly pressure.
- **Field sanitation:** Keep field borders entirely free of weeds.
- **Chemical spray:** Insecticides effective against whitefly adult population: Diafenthiuron 50%WP @ 12g/10L (600 g/ha) or Afidopyropen 50 g/L @ 20mL/10L (1000 mL/ha) or Dinotefuran 20% SG @ 3 g/10L (150g/ha) or Flonicamid 50%WG @ 4 g/10L (200 g/ha) or Clothianidin 50%WDG 1 g/10L (50g/ha) or Pyrifluquinazon 20% WG@10g/10L (500g/ha). Insecticides effective against the

whitefly nymphs are Pyriproxyfen 10% EC @ 20mL/10L (1000 mL) /ha or Buprofezin 25%SC @ 20mL/10L (1000 mL/ha) or Spiromesifen 22.9% SC @ 12 mL/10L (600 mL/ha). Rotate chemical to avoid insecticide resistance in whiteflies..

Crop growth stage: 91–120 DAS

Field actions:

- **Field sanitation:** Do not allow alternate weed hosts to mature or go to seed along irrigation channels or bunds.
- **Chemical spray:** As suggested above.

Crop growth stage: >120 DAS

- **Chemical spray:** Spray Ethion 50EC @ 40 mL/10 L (2000 mL/ha) water for whitefly adults
- **Ratoon crop destruction:** Destroy ratoon cotton crops during the off-season. Leaving cotton stalks standing provides a living bridge for the virus and whitefly populations to survive until the next spring.
- **Off-season weed cleansing:** Continue to remove and destroy alternate weed hosts around the fields even during the fallow period to permanently lower the regional virus inoculum.

12. TOBACCO STREAK VIRUS DISEASE

National importance: Tobacco streak virus (TSV) disease is prevalent in the Southern part of India but also found in Marathwada and Vidarbha region of Maharashtra. TSV is widely distributed worldwide and infects many crops including cotton, soybean, sunflower, and groundnut (Prasada Rao et al., 2009; Vinodkumar et al., 2017). In India, it has become one of the important diseases in Central and South Indian cotton-growing regions.

Causal organism: TSV disease is caused by an RNA virus which is transmitted by thrips. TSV causing RNA virus belongs to the genus *Illarvirus* and family *Bromoviridae*.

Economic impact: Seed cotton yield losses up to 65%.

Disease symptoms : TSV infection in *G. hirsutum* is associated with various types of symptoms. Initial symptoms consisted of chlorotic lesions, which later developed into necrotic, purple-brown spots, occasionally surrounded by yellow halos. The observed spots either chlorotic or necrotic varied in size (ranging from small to large) and pattern, presenting as purplish or purplish-brown irregular or ring-like lesions. These spots are distributed across the interlobular regions, at the apex, or across the entire leaf lamina. In case of severe infection (Grades 3 and 4), drying of squares/bracts and plant stunting are also observed. Furthermore, TSV infection at the seedling stage results in premature plant death (Valarmathi et al., 2023). Infection severity is dependent on thrips multiplication on weeds like Parthenium and movement on the cotton crop. Severe infection causes stunting and

yield reduction (Gawande et al., 2019; 2026).

In *G. barbadense*, the initial leaf symptoms are characterized by distinct, dark purple necrotic spots appearing at 45 DAS, which later spread to the petioles and stems. Other symptoms include necrosis of the crown region and terminal buds, as well as the drying of squares. At later growth stages, the combination of abiotic stress (low temperature) and biotic stress (viral disease) resulted in the partial withering of the cotton squares (Valarmathi et al., 2023).

Chlorosis, leaf malformation & veinal necrosis

Necrotic leaves

Drying of squares

TSV infection in *G.barbadense*

Seasonal disease incidence: Symptoms begin appearing roughly 30–45 DAS. Early indicators show up as distinct chlorotic spots on young leaves, which rapidly transform into characteristic purplish-brown necrotic lesions along the veins, petioles, and squares. The disease progress in August and reaches its absolute peak during the mid-to-late September. This coincides exactly with the peak vegetative and early flowering phases of the cotton crop. As temperatures begin to drop and the crop shifts heavily into boll development, thrips activity subsides. Fresh infection rates dwindle, with active disease incidence dropping by early December.

Disease cycle and epidemiology: The disease cycle of TSV in cotton initiates with the survival of the pathogen in alternative plant hosts and weed reservoirs especially *Parthenium hysterophorus*. Transmission occurs primarily through thrips, which mechanically introduce the virus during feeding by carrying virus-bearing pollen grains from infected weeds or diseased plants onto healthy cotton tissues. Following inoculation, the virus multiplies systemically within the plant's vascular tissues, inducing symptoms such as veinal necrosis, leaf distortion, and terminal bud blight. These infected plants, alongside surrounding weed reservoirs, then function as critical sources of secondary inoculum for further dissemination throughout the cropping season.

Disease surveillance: Initiate weekly monitoring starting from 30 DAS up to 120 DAS to coincide with the peak squaring and flowering phases. Walk the field in 'X' or 'Z' pattern, paying close attention to rows adjacent to field bunds, irrigation channels, and wasteland areas where wild weeds thrive. Inspect 20 cotton plants per acre at random to assess visual symptoms and vector loads. During inspection, observe the progression of chlorotic or necrotic rings, purplish-brown veinal necrosis, and the puckering or wrinkling of young, expanding leaves. Additionally, look for reddish-brown or black necrotic streaks stretching down the petioles and fruiting branches, which frequently cause the affected branches to become brittle.

Deploy blue sticky traps at a rate of 8 traps per acre to monitor thrips. Position the traps slightly above the growing cotton canopy and inspect them weekly. On scouted plants, gently turn over the leaves to record thrips counts from three distinct canopy levels: the top, middle, and bottom leaves. Initiate vector suppression measures if thrips populations average 10 individuals per leaf, or if sticky traps show an exponential influx of adults during the peak flowering window of surrounding weeds.

Economic threshold: The action threshold is reached when populations touch 10 thrips per leaf.

Management strategy:

Pre-sowing

- **Cultivar selection:** Select virus-resistant or tolerant cotton varieties/hybrids appropriate for the specific region.
- **Crop rotation:** Implement strict crop rotation with suitable non-host crop.
- **Field sanitation:** Keep the fields and bunds weed free. Manage Parthenium weeds timely by weeding, hand hoeing or intercultural operations with tractor or bullock to avoid transmission of TSV disease.
- **Intercropping and barrier rows:** Incorporate short-duration, non-host crops such as pearl millet, maize, sorghum, red gram, green gram, black gram, or soybean as intercrops or border rows to break vector movement and reduce overall disease incidence.
- **Fertilizer management:** Apply the optimum recommended dose of nitrogen fertilizer at appropriate split timings. Avoid excess nitrogen, which promotes lush, succulent foliage that accelerates thrips multiplication.

Crop growth stage: 0–60 DAS

- **Parthenium eradication:** Keep fields, bunds, and surrounding areas completely weed-free. Focus aggressively on pulling out Parthenium (*Parthenium hysterophorus*) before it flowers, as it serves as the absolute primary reservoir host for both thrips and TSV.
- **Rogueing:** Regularly inspect young plants. Promptly remove and bury infected leaves or TSV infected seedlings/plants in deep pits to stop secondary viral spread.
- **Blue sticky traps:** Deploy blue sticky traps at a rate of 8 traps per acre for monitoring early arrival. For active mass trapping, scale this up to 40 traps per hectare.
- **Botanical spray (50–60 DAS):** Apply a preventive botanical wash consisting of Neem Seed Kernel Extract (NSKE) @ 50 ml + Neem Oil @ 5 mL/L of water to deter early colonization.
- **Need-based chemical sprays:** If ETL of 10 thrips/leaf is crossed, initiate targeted foliar sprays to suppress vectors and prevent TSV transmission. Spinetoram 11.7 SC @ 425 mL/ha or Flonicamid 50 WG @ 200g/ha or Dinotefuran 20 SG @ 150g/ha or Diafenthiuron 50 WP @ 500 g/ha or Thiamethoxam 25 WG @ 100 g/ha.

Crop growth stage: 61–90 DAS

- **Weed management:** Keep the field margins and irrigation channels completely clear of weeds, ensuring *Parthenium* does not establish a foot-hold.
- **Thrips counting:** Continuously check the traps and calculate numbers by counting thrips from the top, middle, and bottom leaves of randomly selected plants to map overall canopy pressure.
- **Rouging:** Continue physical removal of leaves showing severe necrosis symptoms.
- **Chemical control:** If thrips densities remain above the ETL, rotate above insecticide.

Crop growth stage: 91–120 DAS

- **Thrips management:** Maintain clean field conditions. While mature cotton is tougher, high thrips pressure can still cause crinkling on young terminal leaves and squares.
- **Chemical control:** If needed, above mentioned chemicals can be rotated.

Crop growth stage: >120 DAS

- **Residue clearance:** Immediately after the final picking, pull up cotton stalks and deeply plough the field. Do not allow a ratoon crop to stand over the winter.
- **Off-season weed management:** Continue eliminating *Parthenium* and alternate weed hosts from bunds and adjacent wasteland even when the field is fallow. This drastically drops the viral inoculum and deprives over-wintering thrips of a reproductive host.

Integrated Disease management strategy

Prevention of disease during pre-sowing and at sowing

- Field should be deeply ploughed and left for solarization to expose the soil borne pathogens
- Fields with long history of Fusarium wilt/root rot should be avoided for growing cotton crop.
- Adopt crop rotation, avoid ratoon crop and destroy crop residues.
- Do not allow irrigation water to flow from root rot affected fields to healthy fields.
- Avoid monocropping and cultivation of cucurbitaceous and solanaceous crops in adjoining fields.
- Remove weeds in and around fields.
- Opened boll should be picked immediately to avoid seed borne infection

Chemical and biological control of diseases

Disease	Duration of occurrence	Control measures
Root rot	Seedling to vegetative	Apply $ZnSO_4$ @ 24 kg/ha as soil application. Seed treatment with *Trichoderma harzianium / T. viride* 1% WP @ 4g/kg seed or bio - agent *Pseudomonas fluorescens* @ 10g/ kg seed or Thiram 75% WS 3g/kg seed or Sedaxane 2.5% + Fludioxonil 2.5% + Thiamethoxam 26.25% @ 4 mL/kg seed or Soil drenching with *Trichoderma harzianium / T. viride* 1% WP @ 10 kg/ha mixing with 200kg moist FYM. Spot drenching with Carbendazim 50%WP @ 1 g/L water at the base of affected plants as well as surrounding healthy plants.
Fusarium wilt	Any stage of crop growth	Seed treatment with Thiram 75% WS 3g/kg seed or Sedaxane 2.5% + Fludioxonil 2.5% + Thiamethoxam 26.25% @ 4ml/kg seed or Spot drenching with Carbendazim 50%WP @ 1 g/ L water *Trichoderma harzianium / T. viride* 1% WP @ 25g/10L.
Boll rot	Fruiting stage	Spray Carbendazim 50% WP @ 1 g/L water. For internal boll rot spray with Carbendazim 12% + Mancozeb 63% WP @ 25g / 10L of water.
Alternaria leaf spot	Vegetative and flowering stage	Spray Metiram 55%+ Pyraclostrobin 5% WG 20g /10L water.
Bacterial leaf blight	All stage	Seed treatment with Carboxin 75% WP @ 1.5 g/kg seed or Carboxin 37.5% + Thiram 37.5% DS 2.5 g/kg seed. Foliar spray with Carbendazim 12% + Mancozeb 63% WP @ 25g / 10L of water.

Disease	Duration of occurrence	Control measures
Grey Mildew	Fruiting	Foliar spray of Carbendazim 50 WP 20g or Metiram 55% + Pyraclostrobin 5% WG @ 20g or Propineb 70 WP@ 25-30 g or Kresoxim-methyl 44.3% SC @ 10 mL or Azoxystrobin 18.2% w/w + Difenoconazole 11.4% w/w SC @ 10 mL/10 L water when symptoms seen.

PLANT PARASITIC NEMATODES

National importance: Plant parasitic nematodes act as a "hidden enemy" beneath the surface. They found in all the three cotton growing zones of India especially in irrigated fields. Infestation of nematode severely restricts the uptake of water and vital nutrients, affected cotton plants produce fewer and smaller bolls, results in reduced lint weight and quality, staple length, and strength.

Economic impact: Nematodes are considered hidden and persistent pests because they cause considerable crop damage and yield losses, ranging from 10 to 50 percent under moderate to severe infestation levels.

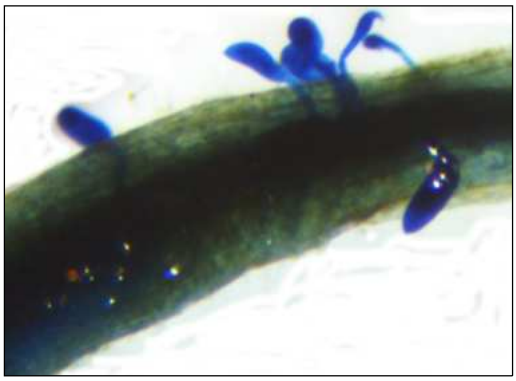
Causal organism: Among the various plant-parasitic nematodes affecting cotton worldwide, root-knot nematode (*Meloidogyne incognita*) and reniform nematode (*Rotylenchulus reniformis*) are recognized as the two most economically important species in cotton-growing regions. The root-knot nematode is one of the most widely distributed and destructive nematode pests affecting cotton and several other crops; it is commonly found in North (Kumar et al., 2020), Central, and certain parts of South India. It's multiplication in cotton is favored in sandy soils. The reniform nematode is serious nematode problems in cotton and soybean, primarily found in Central and South India (Rashmi 1999, Lingaraju et al., 2012). Its multiplication is favored in fine textured soil with a relatively high content of silt or clay. In addition to these two important nematodes Other species of nematodes of minor importance reported on cotton are *Aphelenchus* spp., *Hoplolaimus* spp., Tylenchuss spp. *Pratylenchus* sp. (Rashmi 1999, Lingaraju et al., 2012).

Disease symptoms: Nematode infestations are more common in drip-irrigated cotton monocropping systems. The symptoms caused by nematode damage often resemble nutrient deficiency symptoms; therefore, proper soil testing and diagnosis are essential for making appropriate management decisions.

Root-knot nematode: These microscopic worms enter the young roots and feed on plant tissues, causing the formation of swollen structures known as galls or root knots. As the infestation increases, the normal functioning of the roots is disturbed, leading to poor absorption of water and nutrients from the soil. Root-knot nematode infestation leads to uneven crop growth, pale and stunted plants, and a sickly appearance that often resembles nutrient deficiency symptoms. When the nematode population is high at the time of sowing, seedlings may die at an early stage. In mature plants, temporary wilting during hot summer months is commonly observed. Severely infected plants may produce fewer flowers and bolls, resulting in lower cotton yield and poor lint quality. In some cases, young plants may

dry up or show delayed development. The damaged roots also become more vulnerable to secondary infection by fungi and other soil pathogens, which further weakens the crop. Root-knot nematode problems are generally more severe in sandy or light-textured soils and in fields where cotton is grown continuously without proper crop rotation.

Reniform Nematode: The infestation by reniform nematode does not produce visible root galls like root-knot nematodes. Instead, infected roots appear stunted and slightly thickened, with egg masses attached to the root surface along with fine sandy particles, giving the roots a dirty appearance. This condition is commonly referred to as "dirty root" symptoms. Reniform nematode infested plants exhibit a general decline in growth characterized by dwarfing, chlorosis, and loss of secondary roots. At the third leaf stage, affected seedlings cease rapid growth and develop a light green to pale appearance. Severely infested plants may die, while surviving plants remain stunted, resulting in uneven crop growth across the field. The infected root system becomes smaller and less developed, with browning observed at the points of nematode entry. In the field, patches of stunted plants with pale greenish leaves are a common and characteristic symptom of reniform nematode infestation in cotton. Over the years, the patches of yellowing and stunted plants gradually increase in size and spread across the field.



Reniform nematode infected cotton roots

Root-knot nematode infected cotton roots

Nematode infected plant exhibiting nutrient deficiency symptoms

Uneven crop growth in the field

Photos reproduced from Nagrare et al., 2013

Mark of identification: Plant-parasitic nematodes are tiny, microscopic, thread-like organisms that inhabit the soil. They possess a spear-like mouthpart known as a stylet, which they use to pierce plant roots and suck sap from the tissues.

Root-knot nematode

Eggs: The eggs are small, oval-shaped, and usually covered by a jelly-like protective mass produced by the female nematode. These eggs are generally transparent to creamy white in color and measure about 70–100 µm in length and 30–50 µm in width. Egg masses are commonly seen attached to infected roots or inside root galls.

The second-stage juvenile (J2): It is the infective and most active stage of the nematode. These juveniles are thin, thread-like, and transparent, allowing them to move easily through the soil in search of host roots. They are usually about 350–500 µm long and 15–20 µm wide. A fine needle-like structure called a stylet is present near the mouth region, which helps the juvenile penetrate root tissues and absorb nutrients from plant cells.

Adult female: As development continues inside the root, the female nematode becomes swollen and loses its worm-like appearance. Adult females are typically pear-shaped or round and remain fixed inside the root tissues throughout their life. They are creamy white in color and measure around 0.4–1.3 mm in length and 0.3–0.7 mm in width. Mature females are responsible for egg production, and their posterior region contains specific markings known as perineal patterns, which are useful for species identification.

Adult male: Adult males differ greatly from females in appearance. They regain a slender, worm-like body shape and move freely in the soil after maturity. Males are transparent, elongated, and usually larger than juveniles, measuring about 1.0–2.0 mm in length and 30–40 µm in width. In many root-knot nematode species, reproduction can occur even without males, so males may not always be abundant in infected roots.

Reniform Nematodes

Eggs: The reniform nematode (*Rotylenchulus reniformis*) can be identified at different stages of its life cycle based on body shape, structure, and size. The eggs are oval to slightly elongated and are usually deposited in a gelatinous egg mass outside the root surface. Fresh eggs appear transparent to creamy white and measure approximately 70–90 µm in length and 30–40 µm in width.

Young juveniles: The juvenile stage is slender, worm-like, and transparent, allowing easy movement through the soil. Young juveniles resemble small thread-like worms and gradually develop through several molts before reaching adulthood. The infective immature female is capable of entering the root tissue, while the body remains partly outside the root. Juveniles generally measure about 300–450 µm in length.

Adult females: Adult females are the most distinctive stage of the reniform

nematode. Mature females become swollen and kidney-shaped or reniform after feeding on the roots, which gives the nematode its common name. The posterior part of the body enlarges outside the root surface, while the front portion remains embedded in the root tissue. Adult females are usually creamy white and measure about 0.4–0.8 mm in length and 0.2–0.4 mm in width.

Adult males: Adult males are vermiform, slender, and freely mobile in the soil. They do not feed actively and mainly function in reproduction. Males are transparent and slightly longer than females, measuring around 0.7–1.2 mm in length. Their worm-like body shape clearly differs from the swollen kidney-shaped females.

Seasonal nematode incidence: During sowing to seedling stage, nematode populations in the soil are generally low. The emergence of young, tender radicles triggers the oversummering life stages (eggs and anhydrous juveniles) to activate, moving toward the root zone in response to root exudates. During the squaring to flowering stage, as root volume expands rapidly, it provides an abundant food supply. With optimal environmental conditions, both species complete a generation in roughly 27 to 29 days. This leads to overlapping generations and exponential multiplication, which is when above-ground stunting, chlorosis, and wilting become apparent. Nematode population densities peak sharply at the end of the cropping season. At this stage, soil and root core samples yield the highest counts, as the soil matrix becomes heavily saturated with eggs, juveniles, and semi-endoparasitic females. Peak reproductive activity and the shortest life cycles occur when soil temperatures hover between 28°C and 32°C, while reproduction slows to a near halt when soil temperatures drop below 15°C or climb above 36°C. Consequently, nematode multiplication accelerates during warm pre-monsoon and monsoon windows, whereas winter conditions drive populations into low metabolic survival states.

Nematode life cycle:

Root-knot nematode: The life cycle of root-knot nematode starts when females lay eggs in a gelatinous mass on infected roots. The first-stage juvenile develops inside the egg and moults into the second-stage juvenile (J2), which hatches and enters young roots near the root tip. Inside the root, the juveniles establish feeding sites called giant cells, leading to the formation of characteristic root galls or knots. The juveniles undergo further moults within the root and develop into adult males or females. Adult females remain inside the root and lay about 200–500 eggs in a gelatinous matrix. Under warm conditions, the life cycle is completed within 25–30 days, allowing several generations to develop during a single cotton season. The *M. incognita* reproduces mainly through parthenogenesis, which helps in rapid population build-up in the soil.

Reniform nematode: The life cycle of *R. reniformis* is completed in approximately 17–25 days under favorable conditions. Eggs are deposited in an exposed egg mass on the root surface or in surrounding soil. Juveniles hatch and develop through four juvenile stages (J1 to J4), with J4 females initiating host penetration. In the absence of host plants, *R. reniformis* can persist in the soil for extended periods by entering a state of anabiosis (cryptobiosis), allowing populations to survive unfavorable conditions such as drought and low soil

temperatures. This capacity for dormancy contributes to the persistence of *R. reniformis* in fields even under extended fallow or crop rotation.

Nematode surveillance:

Visual sampling: Nematodes rarely damage a field uniformly; instead, look for oval or circular patches of stunted, yellowing cotton. During flowering, use a shovel to carefully dig up the root ball of an affected plant, gently shake off the soil, and inspect it. Look closely at the roots, if the bead-like swellings (galls) noticed, it is likely a root-knot nematode infestation. If the roots look stunted and blunt but lack galls, a reniform nematode infestation is the probable cause.

Soil sampling: Soil sampling should be carried out when nematode populations are at their peak, either immediately before or right after harvest. Sampling during the cold, dry winter should be avoided, as it can yield low counts. Use a soil probe to collect 20 to 22 separate core samples, digging 6 to 8 inches deep directly into the moist soil of the plant rows where the roots live. Gently mix the cores in a plastic bucket, then place about a quart of the blended soil into a plastic bag. Avoid using paper bags, as they dry out the soil and kill the nematodes, making them impossible for labs to count. Finally, keep the samples out of direct sunlight, store them in a cooler, and ship them to the laboratory as soon as possible for analysis.

Economic threshold: The economic threshold for root-knot and reniform nematodes in cotton is 2 juveniles per cc or g of soil, though these thresholds may vary by region and soil type.

Management strategy:

Nematode infestations are more common in drip-irrigated cotton monocropping systems. The symptoms caused by nematode damage often resemble nutrient deficiency symptoms; therefore, proper soil testing and diagnosis by experts are essential for making appropriate management decisions. In addition, a single strategy is not sufficient for effective nematode management. Integrating different management practices provides a practical and sustainable approach for maintaining nematode populations below the economic threshold. The following recommended practices may be adopted for effective management of nematodes in cotton.

Pre-sowing

- **Deep summer ploughing:** Deep summer ploughing should be performed during the hot summer months. This exposes nematode eggs and juveniles to intense heat and drying, drastically reducing the initial soil population.
- **Soil amendments with non-edible cakes:** Apply cakes of Neem, Karanj, or Mahua to the soil during field preparation or at sowing. These organic amendments release compounds during decomposition that are highly effective against root-knot nematodes.
- **Trap cropping:** Sunnhemp (*Crotalaria spectabilis*) may be used as a trap crop for the management of root-knot and reniform nematodes; the crop should be incorporated into the soil after 30–45 days of growth.

- **Biological control:** Soil application of *Pochonia chlamydosporia* @ 5 kg/ha, mixed with organic manure/vermicompost and incorporated into the soil at sowing, can effectively reduce nematode populations.
- **Crop rotation:** Crop rotation with non-host crops such as wheat, jowar, maize, sesame, mustard, safflower, and millets is an effective strategy for suppressing nematode build-up.

Crop growth stage: 0–60 DAS

- **Weed management:** Maintain weed free field to ensure ensures weeds that do not act as alternative hosts where nematodes can multiply.
- **Vigour management:** Ensure optimal balanced fertilization to help seedlings rapidly outgrow early nematode feeding damage.

Crop growth stage: 61–90 DAS

- **In-season scouting:** Walk the fields to identify early visual indicators. Look for patchy, uneven growth, stunting, or localized yellowing that appears in oval patterns.
- **Moisture management:** Nematode-infested plants have a shallow root system. Maintain precise irrigation schedules to prevent drought stress, as affected plants wilt much faster than healthy ones.
- **Nutrient supplements:** If stunting is visible, a supplemental foliar application of micro-nutrients or potassium can help the plant sustain its fruit load despite root damage.
- **Weed management:** Keep fields strictly clean of weed hosts. Many common field weeds serve as alternative hosts for root-knot and reniform nematodes, allowing them to multiply rapidly.

Crop growth stage: 91–120 DAS

- **Root damage diagnosis:** Use a shovel to dig up the root systems of stunted plants, this will assist in assess of root damage. Inspect for the distinct bead-like galls of Root-knot nematodes. Check for dirty, soil-encrusted roots indicative of Reniform nematodes.
- **Weed management:** Manage weeds to ensure nematodes should not buildup overwintering populations on weed roots.

Crop Growth Stage: >120 DAS

- **Predictive soil sampling:** This is the best time to collect soil samples for laboratory analysis. Sample directly from the root zone while the soil is still moist, immediately before or just after harvest, when nematode populations are at their absolute peak.
- **Post-harvest cultivation:** Destroy stalks and plough out the cotton root systems immediately after harvest. Exposing the roots to the sun and air kills the remaining nematodes and prevents overwintering eggs from maturing.

References

Afroze M, Latif MA, Akhter N, Prodhan MDH, Jahan S (2024) Biology, morphometry and damage assessment of Papaya mealybug, *Paracoccus Marginatus* Williams and Granara De Willink (Hemiptera: Pseudococcidae). Bangladesh J Agril Res 49(2): 175–188.

Agrawal A, Venkatesan T, Ramasamy GG, Syamala RR, Muthugounder M, Rai A (2020) Transcriptome alterations of field-evolved resistance in *Pectinophora gossypiella* against Bt Bollgard II cotton in India. J Appl Entomol 144(3): 929–940.

Ali A, Choudhury RA, Ahmad Z, Rahman F, Khan FR, Ahmad SK (2009) Some biological characteristics of *Helicoverpa armigera* on chickpea. Tunis J Plant Prot 4: 99–106.

Amutha M, Rachana RR (2023) Species diversity of thrips on cotton. Indian J Entomol 85(1): 78-82.

Ashwini SB, Ashoka J, Bheemanna M, Hanchinal SG (2016) Biology and morphometry of *Spodoptera litura* (Fab.) on cabbage. J Exp Zool India 19:1375–1377.

Batson WE (2001) Boll rots. In: T.L. Kirkpatrick and C.S. Rothrock, editors, Compendium of cotton diseases. American Phytopathological Society, St. Paul, MN. p. 36–38.

Belot JL, Zambiasi TC (2007) Manual de identificação das doenças, deficiênciasminerais e injúrias no cultivo do algodão. BoletimTécnico, 36COODETEC/CIRAD-CA, Cascavel, 95.

Borkar SG, Verma JP, Singh RP (1980) Transmission of *Xanthomonas malvacearum* (Smith) Dowson, the incitant of bacterial blight of cotton through spotted bollworms. Indian J Entomol 42: 390-397

Cook D, Herbert A, Akin DS Reed J (2011) Biology, crop injury, and management of thrips (Thysanoptera: Thripidae) infesting cotton seedlings in the United States. J Integ Pest Mngmt 2(2): 1-9

Dhurua S, Gujar GT (2011) Field-evolved resistance to Bt toxin Cry1Ac in the pink bollworm, *Pectinophora gossypiella* (Saunders) (Lepidoptera: Gelechiidae), from India. Pest Manag Sci 67(8):898-903.

Fabrick JA, Jeyakumar P, Singh A, Tanwar RK, Unnithan GC, Yelich AJ, Li X, Carriere Y,Tabashnik BE (2014) Alternative splicing and highly variable cadherin transcripts associated with field-evolved resistance of pink bollworm to Bt cotton in India. PLOS One 9(5): e97900.

Fand BB, Nagrare VS, Bal SK, Naik VCB, Naikwadi BV, Mahule DJ, Gokte-Narkhedkar N, Waghmare VN (2021) Degree day-based model predicts pink bollworm phenology across geographical locations of subtropics and semi-arid tropics of India. Sci Rep 11(1): 1–18

Fand BB, Nagrare VS, Deshmukh V, Naikwadi BV, Gokte-Narkhedkar N, Waghmare VN (2020) A simple and low-cost laboratory rearing technique for pink bollworm, *Pectinophora gossypiella* (Suanders) (Lepidoptera: Gelechidae) using detached green bolls of cotton. Phytoparasitica, 48(1): 25-33.

Fand BB, Nagrare VS, Gawande SP, Nagrale DT, Naikwadi BV, Deshmukh V, Gokte-Narkhedkar N, Waghmare VN (2019) Widespread infestation of pink bollworm, *Pectinophora gossypiella* (Saunders) (Lepidoptera: Gelechidae) on Bt cotton in Central India: a new threat and concerns. Phytoparasitica 47(3): 313–325.

Fand BB, Shah V, Nagrale DT, Mahule DJ, Gawande SP, Thube SH, Pandiyan K, Ramteke I, Kumar R, Rameash K, Prabhulinga T, Nagrare VS, Behere GT, Prasad YG. (2025). Field estimates of current and predicted cotton yield loss due to pink bollworm and boll rot in India. Agric Syst 224:104246.

Fand BB, V Shah, DT Nagrale, DJ Mahule, SH Thube, SP Gawande,VS Nagrare, GT Behere, YG Prasad (2026) Dynamics of economic injury levels for cotton pink bollworm (*Pectinophora gossypiella* Saunders) in relation to control cost, cotton price and control efficacy. J Cotton Res 9(1): 12.

Ferre J, Van Rie J (2002) Biochemistry and genetics of insect resistance to *Bacillus thuringiensis*. Annu Rev Entomol 47(1): 501-533.

Gawande SP, Raghavendra KP, Monga D, Nagrale DT, Kranthi S (2019). Rapid detection of Tobacco streak virus (TSV) in cotton (*Gossypium hirsutum*) based on Reverse Transcription Loop Mediated Isothermal Amplification (RT-LAMP). J Virol Methods 270: 21-25.

Gawande SP, Sain SK, Nagrale DT, Hiremani NS, Meshram MD, Behere GT, Waghmare VN (2026) New report on occurrence of Tobacco streak virus in upland cotton (*Gossypium hirsutum*) in North-Western India. J. Phytopathol. 174(1): e70245.

Gusain A, Semwal A, Maheshwari S, Nautiyal P, Rai D, Raghav D, Singh T (2023) Evaluation of life cycle of gram pod borer *Helicoverpa armigera* (Hubner) on vegetable pea. Int J Plant Soil Sci, 35(22): 731-735.

Guthrie D, WhitmanK, BatsonB, Crawford J, Jividen G (1994) Boll rot. Cotton Physiol Today 5(8).

ICAC (2025) ICAC COTTON DATA BOOK 2025. International Cotton Advisory Committee Washington DC, USA

Jakkoksung A, Attasopa K, Chiu Chun-I, Chanbang Y (2023) Life cycle and damage patterns of Tea mosquito bug (*Helopeltis theivora* Waterhouse), a newly recorded pest on arabica coffee in Northern Thailand. Chiang Mai J Sci 50(5): 1–10.

Jambagi SR, Mohan M, Venkatesan T, Mohan Rao A, Murali Mohan K, Nagesha N (2023) Relative Response of Pink bollworm, *Pectinophora gossypiella* (Saunders) population towards Bollgard-II® Bt Cotton expressing Cry1Ac+Cry2Ab toxins. Mysore J Agric Sci 57(4): 364–371.

Kalia V, Kumari A, Mittal A, Singh BP, Nair R, Gujar GT (2006) Temporal variation in susceptibility of American bollworm, *Helicoverpa armigera* to *Bacillus thuringiensis* (Bt) var. kurstaki HD-73, its Cry1Ac Toxin and Bt Cotton. Pestic Res J 18(1): 47–50.

Kaur R, Kular J S and Chandi R S (2014) Economic threshold level and population dynamics of *Thrips tabaci* on Bt cotton. J Insect Sci 27: 250–253.

Kirkpatrick TL, CS Rothrock (Eds.) (2001) Compendium of cotton diseases (2nd ed.). American Phytopathological Society (APS Press)

Kranthi KR, Kranthi S, Wanjari RR (2001) Baseline toxicity of Cry1A toxins to *Helicoverpa armigera* (Hubner) (Lepidoptera: Noctuidae) in India. Int J Pest Manage 47(2):141–145.

Kukanur VS, Singh TVK, Kranthi KR, et al. (2018) Cry1Ac resistance allele frequency in field populations of *Helicoverpa armigera* (Hübner) collected in Telangana and Andhra Pradesh, India. Crop Prot 107:34–40.

Kumar R, Bhede BV, Paul D et al. (2025) Resistance development in pink bollworm (*Pectinophora Gossypiella* Saunders) against Bt cotton and its' establishment as mid-season pest in India. Sci Rep 15:7012

Kumar R, Paul D, Singh S, Cheema RS (2023) Changing dynamics of thrips infestation-A threat to cotton in the North Zone. Cotton Statistics & News. Cotton Association of India, Mumbai 25: 1–4.

Kumar V, Banakar P, Kumar A and Duggal P (2020) Survey of plant-parasitic nematodes associated with cotton in Nuh and Palwal districts of Haryana. Int J Econ Plants 7(1):44–48

Lingaraju S, Sonavane P, Jamadar MM, Harlapur SI, Bhat RS, Udikeri SS (2012) Plant parasitic nematodes associated with Bt cotton. Curr Sci, 103(8): 926–932.

Malinga LN, Laing M (2024) Lifecycle, hosts and importance of some of the major cotton insect pests in South Africa: A Review. Asian J. Biol. Sci 17 (4): 624–639.

Mohan KS, Ravi KC, Suresh PJ, Sumerford D, Head GP (2016). Field resistance to the *Bacillus thuringiensis* protein Cry1Ac expressed in Bollgard® hybrid cotton in pink bollworm, *Pectinophora gossypiella* (Saunders), populations in India. Pest Manag Sci 72(4): 738–746.

Monga, D. and Raj, S. (1997). Effects of fungicides on cotton root rot pathogen and Bio-control agents. J. Cotton Res. and Dev, 11(2), pp.272-275.

Nagrale DT, Gawande SP, Gokte-Narkhedkar N, Waghmare VN (2020) Association of phytopathogenic *Pantoea dispersa* inner boll rot of cotton (*Gossypium hirsutum* L.) in Maharashtra state, India Eur J Plant Pathol 158: 251-260.

Nagrare VS, Fand BB, Naikwadi BV & Deshmukh V (2021) Potential risk of establishment and survival of cotton aphid *Aphis gossypii* in India based on simulation of temperature-dependent phenology model. Int J

Pest Manage 67(3): 187–202.

Nagrare VS., Bisane KD, Deshmukh AJ, Kranthi S (2012) Studies on life cycle parameters of leafhoppers, *Amrasca biguttula biguttula* (Ishida). Entomon 37 (1-4): 93-99.

Nagrare VS, Naik VCB, Fand BB, Gawande SP, Nagrale DT, Gokte-Narkhedkar N, Waghmare VN (2019). Cotton: Integrated Pest and Disease Management. Technical bulletin, ICAR-Central Institute for Cotton Research, Nagpur.

Nagrare VS, Naikwadi Bhausaheb, Fand BB, Naik VCB, Prabhulinga T, Gokte-Narkhedkar N and Waghmare VN (2025) Seasonal population trend and relative occurrence of pests and their natural enemies among cotton species and cultivars in India. J Cotton Res 8:12

Nagrare VS, Gawande SP, Nagrale DT, Thakare VS, Baghele DJ, Biradar VK, Nikoshe AP, Meshram M, Narkhedkar NG, Waghmare VN (2024) Genetic diversity and Species prevalence revealed by Mitochondrial COI- DNA sequence of thrips population in cotton. J Environ Biol 45: 737-747.

Nagrare VS, Kranthi S, Biradar VK, Zade NN, Sangode V, Kakde G, Shukla RM, Shivare D, Khadi BM, Kranthi KR (2009) Widespread infestation of the exotic mealybug species, *Phenacoccus solenopsis* (Tinsley) (Hemiptera: Pseudococcidae) on cotton in India. Bull Entomol Res 99: 537-541

Nagrare VS, Naikwadi B, Deshmukh V, Kranthi S (2018) Biology and population growth parameters of the cotton mealybug, *Phenacoccus solenopsis* Tinsley (Hemiptera: Pseudococcidae), on five host plant species. Anim Biol 68 (4) : 333-352.

Naik VCB, Kranthi S, Kumbhare S, Dharajothi B, Kranthi KR (2018) Field-evolved resistance of pink bollworm to Bt cotton in India. Pest Manage Sci74(11): 2547-2557.

Paul, S. K., Adam, N. A., Jamian, S., & Mokhtar, A. S. (2025). Life Table and Demographic Parameters of *Helopeltis theivora* Waterhouse (Hemiptera: Miridae). J Exp Biol Agric Sci 13(3): 355-363.

Peddu H, Fand BB, Sawai HR, Lavhe NV (2020) Estimation and validation of developmental thresholds and thermal requirements for cotton pink bollworm *Pectinophora gossypiella*. Crop Prot127:104984.

Perane RR, Gaikawad SB, Pawar NB (2015) Fungi associated with boll rot of cotton and their management. J Cotton Res Dev 29(1): 116-120.

Prasad BMVS, Bhattiprolu SL, Kumar VM, Jayalalitha K and Kumar DVSR (2022) First report of *Corynespora cassiicola* causing target spot on cotton (*Gossypium hirsutum*) in South India. Disease note: 2255 https://doi.org/10.1094/PDIS-11-21-2597-PDN

Prasad BMVS, Bhattiprolu SL, Kumar VM, Jayalalitha K, Kumar DVSR (2025a) Progression of Corynespora Target Spot and estimation of yield losses in cotton. IJBSM 16(10): 1-8

Prasad BMVS, Bhattiprolu SL, Kumar VM, Jayalalitha K, Kumar DVSR (2025b) Integrated management of *Corynespora cassiicola* (Berk. and Curt.) Wei. causal agent of target spot disease in cotton. JBSM 16(9): 01-13

Prasada Rao, RDVJ., Jyotsna, M.K., Reddy, AS., Varaprasad, KS., Nigam, SN, Lava Kumar, P. (2009) Non-systemic infection of Tobacco Streak Virus on Cotton in Warangal district, Andhra Pradesh. Indian J Plant Prot 37(1&2):196-198

Rajveer, Mishra VK, Chauhan D, Bisht RS (2016) Studies on biology and life history of okra shoot and fruit Borer *Earias vittella* (Fabricius) under laboratory condition. J Exp Zool India19(2): 1027-1032.

Rakhesh S, Hanchinal SG, Bheemanna M, et al. (2026) Comparative biology and morphometrics of pink bollworm, *Pectinophora gossypiella* (Saunders) on Bt cotton and alternate malvaceous hosts. Sci Rep 16: 12496.

Rangaraju HT (2025). Studies on cry toxin susceptibility in field populations of *Helicoverpa armigera* (Hübner). M.Sc. Thesis submitted to ICAR-Indian Agricultural Research Institute, New Delhi.

Ranjith MT, Prabhuraj A, Srinivasa YB (2010) Survival and reproduction of natural populations of *Helicoverpa armigera* on Bt-cotton hybrids in Raichur, India. Curr Sci 99(11):1602-1606.

Rashmi HJ (1999) Studies on plant parasitic nematodes of cotton with special reference to *Rotylenchulus*

reniformis Linford & Oliveira. Master thesis submitted to Department of Plant Pathology, College of Agriculture, University of Agricultural Sciences, Dharwad.

Saha, J, Chakraborty K and Chatterjee T (2016) Biology of Cotton aphid Aphis gossypii Glover. J Glob Biosci 5 (8): 4467-4473

Sahana KB, Navi S, Vijaykumar L, Kumar CS, Kumar VBS, Somu G, Chikkarugi NM (2023) Incidence of Mirid Bug species complex in Bt and Non-Bt cotton genotypes. Indian J Entomol 85(3): 697-700.

Sain SK, Monga D, Sabesh M, Prasad YG, Prakash AH and Singh RK. (2023). Disease and Disorders of cotton: A field Guide for symptom-based identification and management. pp 140

Sain SK, Gawande SP, Kumar V, Chandrashekar N, Prakash AH and Prasad YG (2026) First report of target spot caused by *Corynespora cassiicola* on cotton in northwestern India. Plant Disease 108(2): 530.

Salunkhe VN, Gawande SP, Nagrale DT, Narkhedkar NG, Hiremani NS, Waghmare VN (2019) First report of corynespora leaf spot of cotton caused by *Corynespora cassiicola* in central India. Plant Disease, 10.1094/PDIS-05-18-0823-PDN

Saveer AM, Hu J, Strickland J, Krueger R, Clafford S, Zhang A (2024) Reproductive behavior and development of the global insect pest, Cotton Seed Bug *Oxycarenus hyalinipennis*. Insects, 15, 65.

Singh TVK, Kukanur VS (2021) Frequency of resistance alleles to Cry1Ac toxin from cotton bollworm, *Helicoverpa armigera* (Hübner) collected from Bt-cotton growing areas of Telangana state of India. J Invertebr Pathol 183:107559.

Srinivasan KV (1994) Cotton Diseases. Indian Soc. Cotton lmprov, Bombay. 311p.

Taneja NK (1988) *Bortrydiplodia theobromae* on cotton seeds - A new report from India. ISCI J. 13: 176 - 177.

Udikeri SS, Kranthi KR, Patil SB, Modagi SA, Vandal NB (2010) Bionomics of mirid bug, *Creontiades biseratense* (Distant) and oviposition pattern in Bt cotton. Karnataka J Agric Sci 23(1): 153-156.

Valarmathi P, Kanjana D, Sankaranarayanan K (2025) Influence of weather variables on progression of rust disease (*Phakopsora gossypii*) in Cotton. Agric Sci Dig, 1-7.

Valarmathi P, Sampathkumar A, Amutha M, PrakashAH, Prasad YG (2023) Necrosis disease (Tobacco Streak Virus - TSV) of Cotton: Symptoms and Integrated management practices (English Folder). P 1--8.

Vennila S, Deshmukh AJ, Pinjarkar D, Agarwal M, Ramamurthy VV, Joshi S, Kranthi KR, Bambawale OM (2010) Biology of the mealybug, *Phenacoccus solenopsis* on cotton in the laboratory. J Insect Sci 10:115

Verma JP, Singh RP (1971) Epidemiology and control of bacterial blight of cotton. Proc Indian Natl Sci Acad, B37:326-331

Vinodkumar S, Nakkeeran S, Malathi VG, Karthikeyan G, Amala Balu P, Mohankumar S, Renukadevi P (2017) Tobacco streak virus: an emerging threat to cotton cultivation in India. Phytoparasitica 45: 729-743

Wang Y, Watson GW, Zhang R (2010) The potential distribution of an invasive mealybug *Phenacoccus solenopsis* and its threat to cotton in Asia. Agric For Entomol 12: 403-416.

Watkins GM (1981) Compendium of cotton diseases. American Phytopath. Soc. 87 p.

Yao Q, Lin YZ, Qin S, Lin ZF and Ji XC (2025) Characterization of feeding damage by tea mosquito bug, *Helopeltis theivora* Waterhouse (Hemiptera: Miridae) on Hainan Dayezhong tea cultivar. Front Plant Sci 15:1529535.

Zancan WLA,Chitarra LG, Chitarra GS (2011) Fungosassociados à podridão de maçãs do algodoeironaregião de Primavera do Leste, MT, Brasil: ocorrência, controlequímico e influêncianaqualidade da Fibra. Bioscience Journal, Uberlândia, 27 4 518525, 1981-3163.

Zancan WLA, ChitarraLG, Chitarra GS (2013) Cotton in Brazil: Importance and chemical control of bolls rot. In: fungicides - showcases of integrated plant disease management from around the world (Eds:Mizuho Nita), published by Infotech Open, London. DOI: 10.5772/53344.

978-93-93826-00-8

ICAR-CENTRAL INSTITUTE FOR COTTON RESEARCH

Post Bag No 2, Shankar Nagar P. O., Nagpur - 440010 (M.S.), India