



Handbook of
COTTON
PLANT HEALTH

CENTRAL INSTITUTE FOR COTTON RESEARCH

Handbook of **Cotton Plant Health**



V.S. Nagrare, S. Kranthi, K. R. Kranthi, V. Chinna Babu Naik,
Rishi Kumar, B. Dharajothi, S.S. Udikeri, A.K. Mukherjee,
P. K Mukherjee, D. Monga, A.Sampath Kumar, N.G. Narkhedkar,
Gulsar Banu, A.R.Raju, A. S. Tayade, A.H. Prakash, S.E.S.A. Khader

An output of TMC MM I (2007-2012)



CENTRAL INSTITUTE FOR COTTON RESEARCH
Post Bag No.2, Shankar Nagar P.O., Nagpur - 440010

Authors

Name of authors	Contribution
V.S. Nagrare, S. Kranthi, K.R. Kranthi, V. Chinna Babu Naik, Rishi Kumar, B. Dharajothi, S.S. Udikeri*	Insect pests, Biocontrol agents, Pest management
A.K. Mukherjee, P.K. Mukherjee, D. Monga, A. Sampath Kumar	Cotton diseases and their management
N. G. Narkhedkar, J. Gulsar Banu	Plant parasitic & Entomopathogenic nematodes
A.H. Prakash, S.E.S.A. Khader	Physiological disorders and abiotic stresses
A.R. Raju, A.S. Tayade**	Integrated weed management

*College of Agriculture, Bijapur-586 101, Karnataka

**Sugarcane Breeding Institute, Coimbatore, Tamil Nadu

Citation

Nagrare V.S., Kranthi S., Kranthi K.R., Chinna Babu Naik V., Rishi Kumar, Dharajothi B., Udikeri S.S., Mukherjee A.K., Mukherjee P.K., Monga D., Sampath Kumar A., Narkhedkar N.G., Banu Gulsar J., Raju A.R., Tayade A.S., Prakash A.H., Khader S.E.S.A. (2013). Handbook of Cotton Plant Health, Central Institute for Cotton Research, Nagpur p: 100

Published by:

Dr. K.R. Kranthi

Director

Central Institute for Cotton Research

Post Bag No.2, Shankar Nagar P.O., Nagpur 440010

Website: www.cicr.org.in

Printed : Dec. 2013

Printed at : M/s Surya Offset, Ramdaspath, Nagpur

All authors are equal contributors.

Price : Rs. 200/-

Preface

Chapter 1 : Introduction	1
--------------------------------	---

Chapter 2 : Current status of insect pests and their management	2
---	---

Pest complex of cotton

Sap sucking insects

1. Leafhopper <i>Amrasca biguttula biguttula</i> (Ishida).....	3
2. Aphid <i>Aphis gossypii</i> Glover.....	4
3. Thrips <i>Thrips tabaci</i> Lind.	6
4. Whitefly <i>Bemisia tabaci</i> (Gennadius)	7
5. Cotton mealybug <i>Phenacoccus solenopsis</i> Tinsley	9
6. Papaya mealybug <i>Paracoccus marginatus</i> Williams and Granara de Willink	10
7. Spherical mealybug <i>Nipaecoccus viridis</i> (Newstead)	11
8. Pink hibiscus mealybug <i>Maconellicoccus hirsutus</i> (Green)	12
9. Striped mealybug <i>Ferrisia virgata</i> (Cockerell)	13
10. Malvastrum mealybug <i>Ferrisia malvastra</i> (McDaniel)	14
11. Mango mealybug <i>Rastrococcus iceryoides</i> (Green)	14
12. Ber mealybug <i>Perissopneumon tamarindus</i> (Green)	15
13. Indian cotton mirid <i>Creontiades biseratense</i> (Distant)	16
14. Mirid <i>Campylomma livida</i> Reuter	17
15. Mirid <i>Hyalopeplus lineifer</i> Walker	18
16. T Mosquito bug <i>Helopeltis bradyi</i> Waterhouse	19

Cotton bollworms

1. American bollworm <i>Helicoverpa armigera</i> (Hubner).....	20
2. Spotted bollworm <i>Earias insulana</i> (Boisduvel), <i>E. vittella</i> (Fab.)	21
3. Pink bollworm <i>Pectinophora gossypiella</i> (Saunders)	22

Other insects

1. Tobacco caterpillar <i>Spodoptera litura</i> Fabricius	24
2. Cotton semilooper <i>Anomis flava</i> Fabricius	25
3. Cotton leaf folder <i>Sylepta derogata</i> (Fabricius)	26
4. Safflower caterpillar <i>Condica capensis</i> (Guenee)	26
5. Stem weevil <i>Pempherulus affinis</i> (Faust).....	27
6. Flower bud maggot <i>Dasineura gossypii</i> Fletcher	28
7. Red cotton bug <i>Dysdercus cingulatus</i> Fab.	29
8. Dusky cotton bug <i>Oxycarenus hyalinipennis</i> (Costa).....	30
9. Green weevil <i>Tanymecus princeps</i> Faust	30
10. Cotton grey weevil <i>Myllocerus maculosus</i> Desb.	31

Biological control agents

Predators

1. Lady bird beetle <i>Cheilomenes sexmaculata</i> (Fabricius)	31
2. Lady bird beetle <i>Cryptolaemus montrouzieri</i> (Mulsant).....	32
3. Lady bird beetle <i>Scymnus coccivora</i> Ayyar.....	33
4. Lady bird beetle <i>Nephus regularis</i> (Sicard)	33
5. Lace wings <i>Chrysoperla carnea</i> (Stephans)	34
6. Hover fly <i>Eupeodes confrater</i> (Wiedemann)	34
7. Spiders	35
8. Predatory stink bug, <i>Eocanthocona furcellata</i> (Wolff)	36

9. Dipteran fly <i>Cacoxenus perspicax</i> (Knab)	36
10. Apefly <i>Spalgis epius</i> (Westwood)	36
11. Big eyed bug <i>Geocoris ochropterus</i> (Fieber)	37
Parasitoids	
1. <i>Aenasius bambawalei</i> Hayat	37
2. <i>Metaphycus</i> sp.	38
3. <i>Anagyrus kamali</i> Moursi	38
4. <i>Anagyrus dactylopii</i> (Howard).....	39
5. <i>Anagyrus mirzai</i> Agarwal and Alam	39
6. <i>Homalotylus albiclavatus</i> (Agarwal)	39
7. <i>Chartocerus kerrichi</i> (Agarwal).....	39
8. <i>Pachyneuron leucopiscida</i> Mani	39
9. <i>Palexorista laxa</i> Curran	40
10. <i>Rogas aligarhensis</i> Quadri	40
11. <i>Campoletis chlorideae</i> Uchida	40
12. <i>Apanteles anguleti</i> Muesebeck	40
13. <i>Acerophagus papayae</i> Noyes & Schauff.....	41
14. <i>Aprostocetus</i> sp.	42
15. <i>Aprostocetus bangaloricus</i> Narendran	42
16. <i>Encyrtus aurantii</i> (Geoffroy)	42
17. <i>Bracon greeni</i> Ashm	42
18. <i>Bracon lefroyi</i> (Dudgeon & Gough)	42
19. <i>Microchelonus versatilis</i> (Wilkinson)	43
20. <i>Aphelinus</i> sp.	43
21. <i>Trichogramma chilonis</i> Ishida	43
Hyperparasitoids	
1. <i>Promuscidea unifasciativentris</i> Girault	43
2. <i>Prochiloneurus albifuniculus</i> (Hayat et al.)	43
3. <i>Prochiloneurus pulchellus</i> Silvestri	44
4. <i>Prochiloneurus aegyptiacus</i> (Mercet)	44
5. <i>Homalotylus eytelweinii</i> Ratzeburg	44
Pathogens of cotton insect pests	
1. <i>Nomuraea rileyi</i> (Farlow) Samson	45
2. Nuclear polyhedrosis virus	45
3. Entomopathogenic nematodes	45
4. Bacterial symbionts as source of new insecticidal toxin genes	46
Pest management strategies	
1. Pre season and in-season cultural, mechanical and physical methods for minimizing pest population	47
2. Pest surveillance	49
3. Economic threshold levels (ETLs)	49
4. Pictorial representative of sucking pest grades	51
5. Advisory for probable situations of insect pest incidence	53
6. Do's and don'ts in IPM/IRM	55
8. Details of insecticides suggested against cotton pests	58
9. Classification of the insecticides based on Toxicity	61
10. Calculation of insecticide doses	61
Chapter 3 : Cotton diseases and their management	62
Fungal diseases	
1. Root rot	62

2. Fusarium wilt	63
3. <i>Verticillium</i> wilt	64
4. Grey Mildew	64
5. Alternaria leaf spot	66
6. Myrothecium leaf spot	67
7. Rust	68
8. Boll rot	68
Bacterial diseases	
1. Bacterial leaf blight	69
Viral diseases	
1. Cotton leaf curl disease	70
2. Tobacco streak virus disease	71
3. Cotton blue disease	72
Disease management	
1. Prevention of diseases during pre-sowing and at sowing	73
2. Chemical and biological control of diseases	74
Chapter 4 : Plant parasitic nematodes	76
1. Recognizing plant damage caused by nematodes	76
2. Clues for diagnosis of nematode disease	77
3. Symptoms of nematode damage	77
4. Sampling the field for detection of nematodes	77
5. Root knot nematode <i>Meloidogyne incognita</i> (Kofoid and White, 1919)	77
6. Reniform nematode <i>Rotylenchulus reniformis</i> Linford and Oliveira, 1940	78
7. Estimating root knot nematode infection	79
8. Strategies for nematode management	80
Chapter 5 : Physiological disorders and abiotic stresses	81
1. Fruit shedding (abscission)	81
2. Square and boll drying	82
3. Leaf reddening	82
4. Parawilt/ New wilt	83
5. Premature senescence	84
6. Fertilizer burn	84
7. Herbicide damage	84
8. Gall like structures	85
9. Drought	86
10. Salinity	86
11. Water logging	87
Chapter 6 : Integrated weed management	88
1. Common weed flora observed in cotton	88
2. Land preparation	89
3. Pre sowing herbicides	89
4. Pre plant herbicide application	90
5. Pre emergence herbicides	90
6. Post emergence weed management	90
7. Safe period in rotations and sequential cropping	91
8. Precautions	91
9. Herbicide resistant weeds	92
10. Herbicide resistant cotton	92
References	94

Abbreviations

a.i.	Active ingredient
AICCIP	All India Coordinated Cotton Improvement Project
ABW	American bollworm
APHIS	Animal and Plant Health Inspection Service
@	At the rate
Bt	<i>Bacillus thuringiensis</i>
CICR	Central Institute for Cotton Research, Nagpur
CRIDA	Central Institute for Dryland Agriculture, Hyderabad
CLCuD	Cotton leaf curl disease
cc	Cubic centimeter
DAI	Days after inoculum
DAS	Days after sowing
°C	Degree Celsius
DAP	Di ammonium phosphate
ft	Feet
GEAC	Genetic Engineering Appraisal Committee, New Delhi
g	Gram
G	Granules
ha	Hectare
HNPV	Helicoverpa Nuclear Polyhedrosis Virus
HDPS	High Density Planting System
h	Hour
IARI	Indian Agricultural Research Institute, New Delhi
ICAR	Indian Council of Agricultural Research, New Delhi
IRM	Insecticide resistance management
IPM	Integrated pest management
IOBC	International Organization for Biological Control
kg	Kilogram
LE	Larval equivalent
l	Liter
m	Meter
µL	Microliter
mm	millimeter
NAIP	National Agricultural Innovation Project
NSKE	Neem seed kernel extract
PBW	Pink bollworm
RH	Relative humidity
RR Flex	Round-up ready Flex
SCY	Seed cotton yield
SBW	Spotted bollworm
TMC MM I	Technology Mission on Cotton Mini Mission I
TC	Tobacco caterpillar
TSV	Tobacco Streak Virus
USDA	U.S. Department of Agriculture
UV	Ultra violet
UAS	University of Agricultural Sciences, Dharwad
USA	United States of America
WHO	World Health Organization

Preface

Cotton is an important cash crop and India cultivates the highest acreage in the world. Wide gaps persist in productivity due to several biotic and abiotic stresses that become unmanageable due to late and improper diagnosis of the problem. In the post-Bt era, as a result of widespread cultivation of hybrids, crop management practices have changed, and have become more input-intensive. Also, the uniformity of genotypes across vast areas is likely to favor build-up of epidemics. As a result, growers face several new challenges, and many minor insect pests and pathogens have emerged as major problems threatening cotton cultivation. Plant parasitic nematodes, often referred to as 'hidden pests' have a subtle influence on the health of cotton crop, especially in irrigated tracts. Nematode problems surfaced in the Buldhana district of Maharashtra this year where cotton was being cultivated as a pre-seasonal crop with the help of drip irrigation. This handbook addresses the issues of nematodes in cotton. Weeds cause huge economic losses in all crops including cotton. An attempt has been made to identify important weeds in cotton. Physiological disorders do impact cotton production. Although the phenomenon may not be widespread, it occurs in certain isolated pockets where cotton farmers suffer losses due to physiological disorders. Physiological disorders and suitable amelioration has been suggested.

Handbook of Cotton Plant Health addresses the need for a compact volume which would help the growers, scientists and extension workers to correctly diagnose biotic and abiotic stresses of cotton in field, as correct diagnosis is a prerequisite to a timely solution. We have tried to compile a large number of "real-time" pictures illustrating major insect pests, diseases, nematodes and some common physiological disorders of cotton, along with a brief description of the problem.

We dedicate this handbook to the cotton growers of India.

Acknowledgements

It was a delight to bring out this HANDBOOK OF COTTON PLANT HEALTH. Scientists from different disciplines came together on a common platform for its compilation. More than 95% area in the country is under Bt cotton, despite which emerging pests, diseases, abiotic stresses, weeds, nematodes and physiological disorders continue to cause losses. An attempt has been made to help cotton farmers correctly diagnose these biotic and abiotic problems afflicting cotton.

Dr. V.V. Ramamurthy, Professor, Division of Entomology, IARI, New Delhi who enabled the accurate identification of insect specimens is gratefully acknowledged. The authors are deeply indebted to the project staff Research Associates, Senior Research Fellows, Technical assistants, semiskilled staff who worked in different projects under TMC MM I. Their untiring efforts are gratefully acknowledged.

The authors are indebted to the ICAR and Ministry of Agriculture for financially supporting time bound, issue based, output oriented research under the TMC MM I.

Cotton is being cultivated for its natural fiber in more than 83 countries of the tropic and sub-tropic regions with diverse climatic conditions. In terms of employment generation and national economy, cotton plays a key role in many countries. In India genetically modified cotton popularly known as 'Bt cotton' was introduced in 2002 for bollworm control. With its obvious advantages over non-Bt, Bt cotton occupies about 95% area of the total cotton cultivated area. The visible changes in cotton cultivation shift from non-Bt to Bt cotton initially with single gene (*cry1Ac*, *cry1C*, *cry1F*, *vip3A*) and thereafter with multi-gene (*cry1Ac* + *cry2Ab*,) incorporated in several promising hybrids, not only changed the cultivation profile but also pest pattern significantly during the last decade. Overall insecticide use against cotton pests reduced from 46% in 2001 to less than 26% after 2006 and 21% during 2009 and 2011(CICR, 2011).

In the non-Bt era, cohabitant sucking pests were suppressed with insecticides applied for the control of bollworms. However, reduced insecticide use for the control of bollworms in Bt cotton allowed sucking pest populations to persist season-long. This was further assisted by the cultivation of susceptible Bt hybrids. Population of regular sucking pests viz. leafhoppers (*Amrasca biguttula biguttula* (Ishida), aphids (*Aphis gossypii* Glover), mirids (*Campylomma livida* Reuter, *Creontiades biseratense* Distant), thrips (*Thrips tabaci* Linde.) and whiteflies (*Bemisia tabaci* Genn.) received attention. During the last 5 years new pests have caused significant damage to cotton crop regionally and nationally. Among the emerging pests, 8 species of mealybugs predominantly *Phenacoccus solenopsis* Tinsley and *Paracoccus marginatus* Williams and Granara de Willink, 3 species of mirids predominantly *Campylomma livida* Reuter and *Creonteades biseratense* (Distant), T Mosquito bug (*Heliopeltis bradyi* Waterhouse), Flower bud maggot (*Dasineura gossypii* Fletcher), Safflower caterpillar (*Condica capensis* Guenee) was seen to damage cotton crop.

Significant changes in the Bt-cotton era were witnessed with disease incidence. Bt hybrids have shown more susceptibility to bacterial blight and *Alternaria* leaf spot as compared to their non-Bt counterparts. Incidence of CLCuD has also increased due to introduction of a number of susceptible Bt cotton hybrids in north zone. A disease identified as TSV transmitted by thrips was observed in the region of Southern Maharashtra, Andhra Pradesh and Tamil Nadu. Among several plant parasitic nematodes reported from the rhizosphere of cotton, root-knot nematode-*Meloidogyne incognita* and reniform nematode- *Rotylenchulus reniformis* have been documented as the most important nematodes infesting cotton.

Physiological disorders, abiotic stresses and weeds deteriorate the health of crop and can reduce yield. In the changed scenario of biotic and abiotic stresses it was felt necessary to consolidate latest information on their status and management to avoid yield losses. We hope this HANDBOOK OF COTTON PLANT HEALTH will be useful for plant protection specialists, farmers, researchers, planners and students.



Bollworms and sap feeding insects caused enormous damage to cotton, prior to 2002 in India. Excessive use of insecticides, nearly 45% (2001) of the total insecticides used on all crops was used on cotton, though area under cotton contributed to just 5%. In 2002, 3 first generation Bt-cotton hybrids were approved for cultivation and thereafter every year a number of hybrids approved by the GEAC were added for cultivation in all the three cotton growing zones. It is estimated that the number of Bt hybrids released by about 30 seed companies is more than a 1000. These Bt hybrids have been inadequately tested for their resistance to sucking pests in the field.

Together, use of plant protection technologies viz., Bt cotton, improved and updated IPM and IRM strategies, reduced overall insecticidal sprays and insecticide use came down by more than 50% during last couple of years. Though, bollworm incidence and insecticide use declined, visible changes in the pest infestation was seen during the last decade as most of the released hybrids were highly susceptible to sucking pest like leafhoppers, whiteflies, thrips, mirids and more recently to invasive mealybugs. As a result insecticide use which had declined to 41% in 2006 gradually increased to 84% in 2010 as compared to base year 2001(100%) (CICR, 2011). In the recent years, 8 species of mealybugs (*Phenacoccus solenopsis*

Tinsley, *Maconellicoccus hirsutus* Green, *Nipaecoccus viridis* Newstead, *Paracoccus marginatus* Williams and Granara de Willink, *Ferrisia virgata* Cockrell, *F.malvastra* (McDaniel), *Rastrococcus iceryoides* (Green), *Perissopneumon tamarindus* (Green), 3 species of mirids (*Creontiades biseratense* Distant, *Campylomma livida* Reuter and *Hyalopepsus lineifer* Walker), T Mosquito bug (*Heliopeltis bradyi* Waterhouse), Flower bud maggot (*Dasineura gossypii* Fletcher), Safflower caterpillar (*Condica capensis* Guenee) was seen to damage the cotton crop significantly.

Information on the individual pest status on cotton and other hosts, distribution in India/World, nature of damage, sampling methodology/techniques, biology, seasonal dynamics, host range, resistance to insecticides, natural enemies, rational management have been described in this chapter.

Pest complex of cotton

Sap sucking insects

1. Leafhopper *Amrasca biguttula biguttula* (Ishida)

Leafhopper, *Amrasca biguttula biguttula* (Ishida) (Homoptera: Cicadellidae) is the most important pest species on cotton in India (Shivanna *et al.*, 2009, Murugesan and Kavitha, 2010). Leafhopper also commonly referred as Indian Cotton Jassid is a season-long sucking pest of cotton. Leafhopper adults are very active, pale green in colour measuring about 3.5mm in length with two distinct black spots on forewings and vertex, readily identified by their characteristic diagonally movement on the



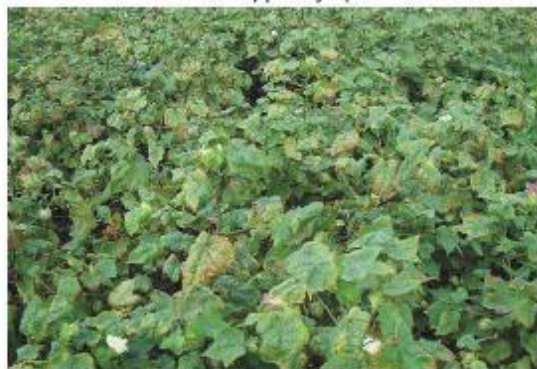
Leafhopper adult



Leafhopper nymph



Leafhopper damage



Leafhopper affected field

leaves hence referred as 'leafhoppers'. Leafhopper infestation significantly reduces chlorophyll and relative water content in cotton (Prabhakar *et al.* 2011).

Population of leafhoppers occurs throughout the season but attain pest status during July-August in central India. Up to eleven generations in a year have been estimated to occur on cotton. Eggs are yellowish white in colour, and intensely rooted in the midribs or large veins on the under surface of the leaves. Nymphal period varied from 5-16 days while adult longevity was of 13.37 ± 5.17 days. Females live slightly longer (23.19 ± 4.86 days) than males (21.38 ± 5.39 days). Both nymphs and adults of leafhoppers suck the cell sap from the plant tissue and inject toxin into it resulting in 'hopperburn' symptoms. The affected leaves show crinkling and curling symptoms almost all over the plant and in extreme situations results in drying of leaves, reduced photosynthetic activity, that hampers the productivity of cotton reducing average cotton yield up to 30%. Besides cotton, it infests brinjal, cacao, pepper, potato etc and is geographically distributed across Afghanistan, Bangladesh, Hong Kong, India, Indonesia, Malaysia, Myanmar, Nepal, Pakistan, Sri Lanka, Thailand, Australia and Pacific islands, Papua New Guinea (CABI, 2013a).

Leafhoppers have been selected for more than one mechanism of resistance (Razaq *et al.* 2006). In the recent study conducted (CICR, 2010) leafhoppers have developed resistance to some of the widely used insecticides like Imidacloprid, Thiamethoxam, Acephate and Monocrotophos by up to 5040, 2500, 110 and 54 fold respectively in some pockets of India. Populations of leafhopper across India are genetically different as indicated through molecular studies at CICR. Leaf trichomes on the plant surface are reported to deter leafhopper incidence and it is widely believed that hairiness confers leafhopper tolerance. Gene bank at CICR houses several glabrous type genotypes that are also leafhopper tolerant. PKV 081, NH 615 and Suraj are 3 varieties that are moderately tolerant to leafhoppers and are found suitable for HDPS. Remote sensing for detection of stress in cotton caused by leafhopper with ground based hyperspectral data revealed narrow bands at 376 and 496 nm (blue), 691 and 715 nm (red), 761 nm (NIR) and 1124 nm (SWIR-1) as sensitive to leafhopper damage and two new leafhopper indices (LHI 2 and LHI 4) have been developed at CRIDA which may have potential use for detecting gradients of leafhopper severity in cotton by remote sensing (Prabhakar *et al.*, 2011).

2. Aphid *Aphis gossypii* Glover

Aphid *Aphis gossypii* Glover (Homoptera: Aphididae) commonly known as cotton aphid or melon aphid is a polyphagous and damaging pest to many economically important crops. Besides cotton it damages important crops such as citrus, coffee, okra, peppers, potato, squash, sesame and cucurbits. The species is distributed in the tropical region. Aphid adults are yellowish brown to black in colour, measuring about 1.25 mm in length with black cornicals and yellowish green abdominal tip. Aphid reproduces parthenogenetically as well viviparously. In a single day female gives birth to 8-22 nymphs. Nymphal period varies between 7-9 days while adult 12-20 days. Annually, 12-14 generations can occur (Vennila *et al.*, 2007a). Polymorphism can be seen in adults with apterous and alates within the population. Nymphs are smaller than adults and are mostly wingless.

Aphids cause direct damage by feeding on the phloem, excretion of honeydew which attracts sooty mould fungus resulting in reduced photosynthesis and plant vigor. Infested leaves exhibit crumpling and downward curling. Indirectly aphids cause deterioration in cotton fiber quality due to deposition of honeydew on open bolls. Younger plant parts suffer more attack than older ones. Aggregating populations are seen at the terminal ends. Largest populations are found on underside of leaves where they are protected from direct sunlight and temperature. Aphid infestation is favored by cloudy weather. Aphids and predatory insects like coccinellids and syrphids share a density dependant relationship especially during the vegetative stage of the crop. Aphids are vectors of virus diseases and are responsible in transmitting cotton anthracnosis virus, cotton curliness virus, cotton blue disease, cotton leaf roll and purple wilt (Kennedy *et al.*, 1962; Brown, 1992). Ant association with aphid infestation is common; facilitate transfer of aphid from one plant to another.

Field distribution is usually clumped and infestation develops along areas downwind from bund. It was experienced that fields receiving regular insecticidal sprays continue to display damage for longer duration as compared to fields without insecticide treatment where natural enemies take care of aphids. Late sown crops are more prone to aphid infestation than early sown crops. Application of excessive nitrogenous fertilizers promotes faster multiplication of aphids. Cloudy weather in the early vegetative growth stage pre-desposes the plants to aphid damage. Assessment of overall field condition is important while opting for its management seed treated with neonicotinoids offers protection up to 45 days.



Adult aphid



Leaf infested with aphid



Shoot infested with aphid



Whole plant infested with aphid and sooty mold

3. Thrips *Thrips tabaci* Lind.

Thrips *Thrips tabaci* Lind. (Thysanoptera: Thripidae) also known as onion thrips, potato thrips is polyphagous pest known to be vector of virus diseases of cotton, tobacco, tomato, pineapple, onion, potato, peach, cabbage, alfalfa, etc., geographically distributed over 100 countries in Europe, Asia, USSR, Africa, Australia, Pacific islands, North, Central & South America, USA, West Indies (CABI, 2013 b). Thrips are small bodied insects measuring about 1mm in length and body colour varies from yellow to brown depending largely on temperatures. Nymphs are creamy to pale yellow in colour resemble the adult but are however wingless. Female lays minute, kidney shaped eggs in slits in leaf tissues. Reproduction is parthenogenetic as males are rare. Eggs hatch in 5 days, nymphs last for 5 days while pupal period extends over 4-6 days. Adults live for 14-28 days. Thrips can produce upto 15 overlapping generations in a year. Population peaks during July-August modulated by rainfall distribution and dry spells with higher temperatures (Vennila *et al.*, 2007b).

Both nymphs and adults lacerate the tissue and de-sap the plants from the upper and lower surfaces of leaves. While feeding they inject saliva and suck lysed contents of plant cells resulting in silvery or brown necrotic spots. Infested plants demonstrate hampered growth, loss of vigor, leaves become wrinkled and distorted, curl upward with white shiny patches. Rusty appearances in patches develop on underside of leaves. Higher infestation during vegetative stage results in late bud formation. Thrips damage results in premature dropping of squares, delayed crop



Thrips adult



Thrips nymph



Silvery patches on the leaf



Severely affected leaf by thrips damage

maturity and reduction in yield. Viral diseases like TSV in cotton transmitted by *T. tabaci* have been recorded in Warangal district of Andhra Pradesh during the months of September and October. Studies have demonstrated that seed treatment with imidacloprid often predisposes the plant to thrips damage under dry conditions. Hot and dry conditions during the early part of the season favours incidence of thrips in cotton crop.

4. Whitefly *Bemisia tabaci* (Gennadius)

Whitefly, *Bemisia tabaci* (Gennadius) (Homoptera: Aleyrodidae) is a polyphagous pest known by several names e.g. tomato, sweet potato, silverleaf whitefly. Whitefly is an important pest of cotton; geographically well distributed in tropical and subtropical regions however restricted in temperate habitats of the globe. Worldwide it has been reported on more than 600 hosts (Oliveira *et al.*, 2001) among them brinjal, chilli, cucurbits, cotton, mentha, okra, potato, rapeseed, sunflower, soybean and tomato are important agricultural crops.

Whiteflies cause both direct and indirect damage to cotton plant. The direct damage is in two forms i.e. sucking the sap and by excreting honey dew on which sooty mould grows. Damage from direct feeding reduces the photosynthetic activities of the plant and hence reduces yield. Indirect damage results from honey dew contamination of lint and associated fungi and through transmission of CLCuD. Management of CLCuD in cotton involves minimal curative measures. Late season damage severely affects the seed development and the lint quality. Symptoms of whitefly damage is seen as upward curling of leaves and reduced plant vigor. Leaves become shiny with sugary secretion or darkened by sooty mould. The harvestable lint is contaminated with sugary liquid and sooty mould if the infestation persists during boll opening period. When whiteflies attack the crop in the late stages after boll opening the quality of cotton is severely affected imparting stickiness to and discolouration of cotton fiber thereby fetching a low market price.

Whitefly is small in size measuring about 1.1-1.2mm in length and has distinct white wing colour, yellow body dusted lightly with waxy powder. On cotton plant about 100-120 stalked and elliptical shape eggs are laid singly on the undersurface of top and middle canopy leaves. Eggs hatch in 3-5 days during warmer period and beyond 30 days in winter. After hatching nymphs secure themselves to the underside of the leaves. Nymphs molt thrice and their period varies from 9-14 days during summer and 17-19 days during winter. Whiteflies have a pupal period from 2-8 days. Depending upon the weather conditions whiteflies complete their life cycle that takes 14 to 107 days. Whiteflies reproduce sexually as well as parthenogenetically, produce 12 generations annually (Vennila *et al.*, 2007c) in central India.

Although whiteflies occur throughout India, it is the most important sucking pest in North Indian cotton growing states of Punjab, Haryana and Rajasthan by virtue of its capability to transmit CLCuD, especially in *Hirsutum* cotton. In these areas, it is not uncommon to see a cloud of whiteflies rise from a severely infested crop, when the plants are disturbed especially during the later part of season. The activity of whiteflies can be seen from the emergence of seedlings to full grown crop. During offseason they survive on the other crops such as crucifers, cucurbits and

malvaceous crops. Warmer period and scanty rainfall situation aggravate the severity of the pest.



Whitefly adult



Whitefly infested plant



Pseudopupa of whitefly



Leaf curl virus affected plant

Mealybugs

Mealybugs are pests of many cultivated and uncultivated crops around the globe. Diversity studies of mealybugs in Indian cotton agroecosystem indicated occurrence of 8 mealybug species. *Phenacoccus solenopsis* Tinsley was the predominant species in north and central zone while *Paracoccus marginatus* Williams and Granara de Willink was the predominant species in south zone. Four mealybug species *Maconellicoccus hirsutus* (Green), *Nipaecoccus viridis* (Newstead), *Ferrisia virgata* Cockrell and *Ferrisia malvastra* (McDaniel) in central zone, *Rastrococcus iceryoides* (Green) in central and south zone while *Perissopneumon tamarindus* (Green) were recorded in north zone in traces. Mealybug nymphs and adults suck sap from all parts of the plant. Plants infested with mealybugs in the vegetative stage show stem distortion, twisting and bushiness of the affected portion. Sooty mold develops on the honey dew secretions that attract ants that act as carrier of crawlers from one plant to another. Late season infestations cause early senescence as a consequence of reduced vigor and significant yield loss. Mealybug infestation in north and central zones ranged from mild (10-20%) to high (40-60%) during 2007 and 2008, were reduced to a minor pest in 2009 (Tanwar *et al.*, 2011) and subsequent crop seasons of 2010, 2011 and 2012.

5. Cotton mealybug *Phenacoccus solenopsis* Tinsley

Cotton mealybug also called solenopsis mealybug *Phenacoccus solenopsis* Tinsley (Homoptera: Pseudococcidae), described originally from US (Tinsley, 1898) is found to infest cultivated cotton in the same country (Fuchs *et al.*, 1991). Widespread outbreak of *P. solenopsis* on cotton in India during 2007 (Nagrare *et al.*, 2009) caused economic damage reducing yields up to 50% in affected cotton fields. Infestation of *P. solenopsis* was seen over large areas with different cropping systems in all nine major cotton growing states. The insect is small measuring about 5 mm, covered by white mealy wax, with dark dorso-submedial bare spots forming 1 pair of dark longitudinal lines on dorsum. *P. solenopsis* is known for its high reproduction capacity producing up to 812 offsprings per female with 95% female progeny on host cotton with several generations in a year. The insect reproduces by obligate sexual reproduction. The developmental period for females was recorded as 13.2 ± 1.8 days, compared to males (18.7 ± 0.9 days). The reproductive period lasted 30.2 ± 8.2 days. Adult females lived 42.4 ± 5.7 days while males lived 1.5 ± 0.1 days (Vennila *et al.*, 2010). The insect body has waxy coating, small size, is able to feed on all plant parts which allow *P. solenopsis* to spread over extensive areas. Molecular studies characterising the mitochondrial genome of individuals at CICR revealed that populations of *P. solenopsis* from India were highly homogenous indicating narrow genetic diversity throughout the country. *P. solenopsis* is polyphagous in nature with wide host adaptability in different climatic conditions around globe; hence they establish and spread readily on other crops of economic



P. solenopsis adult female



P. solenopsis infested boll



Drying of severely infested plant



Severely infested field by *P. solenopsis*

importance. *P. solenopsis* is found to feed on 194 host plants across India (Vennila *et al.*, 2011).

P. solenopsis presents a significant threat to agriculture and horticulture in many tropical and subtropical countries, posing severe threat to cotton production especially in Asia; the climate of many of these cotton-producing areas is favorable for its colonization and establishment (Wang *et al.*, 2010). Hodgson and coworkers (2008) reviewed the morphological differences between *P. gossypiphilous* Abbas, *P. solani*, *P. defectus* and *P. gossypii* and indicated that these species were the environmentally induced variants of single species *P. solenopsis* which is now widespread in India subcontinent.

Distribution of *P. solenopsis* was observed within the cotton plant from vegetative to boll formation stage. In the vegetative and square formation stages, the highest mealybug population was recorded on the upper portion of the stem, followed by the middle leaves of the plant. In the boll formation stage, there was no significant difference in distribution of the insect among plant parts (Kumar *et al.*, 2013). A new sampling plan for *P. solenopsis* has been standardized by CICR. Incidence was assessed based on presence of mealybug and the severity using zero to four scale of infestation. Study indicated the importance of locating the source of mealybug infestation first, and sampling field areas largely parallel to the infestation source. Sample sizes of 25 to 50 plants per acre were sufficient in fields with known source of infestation such as roadside, weeds and water channels. A sample size of 100 plants per acre was necessary for clean fields where prior knowledge of mealybug infestation is not available. Losses in cotton due to the mealybug varied between 14.9% at Grade 1 and 53.6% at Grade 4, on a 0 to 4 severity index, with a mean reduction of yield by 35% and 32%, during 2008 and 2009, respectively. There was a significant relationship between severity of infestation and decrease in seed cotton yield (Kumar *et al.*, 2013).

6. Papaya mealybug *Paracoccus marginatus* Williams and Granara de Willink

Papaya mealybug *Paracoccus marginatus* believed to have originated in Central America was recorded in a severe form for the first time on cotton in Coimbatore. Infestation of *P. marginatus* was observed on *G. arboreum* and *G. hirsutum* species including Bt cotton under field conditions. It was observed that severe infestation led to stunted growth and drying of the sympodial branches. The mealybug infestation can be seen as clusters of cotton-like masses on the leaf, squares and bolls. Papaya mealybug caused havoc in agricultural and horticultural crops ever since its first report from Coimbatore in 2007. The insect assumed the status of a major pest in 2009 when it caused severe damage to economically important crops and huge losses to farmers in Coimbatore, Erode, Tirupur, Salem, Namakkal and Karur districts of Tamil Nadu (Tanwar *et al.*, 2010). The pest was also reported in Karnataka, Andhra Pradesh as well as Kerala and Pune area of Maharashtra subsequently. Recently the pest has been recorded in Nagpur on cotton and Hibiscus. The adult female of the pest is yellowish in colour measuring about 2.2mm covered with white wax while males are 1.0 mm long, pink especially during the pre-pupal and pupal stages. When pressed, yellow body fluid oozes out. Females

usually lay 100 to 600 eggs. Heavy attack of papaya mealybug has been noticed on a wide range of cultivated crops and weed hosts belonging to different families of plant kingdom. *P. marginatus* is found to infest over 84 plant species belonging to 35 families in south India (Selvaraju and Sakthivel, 2011) among them economically important host plants are papaya, citrus, mango, cherry, pomegranate, hibiscus, cotton, jatropha, cassava, egg plant, potato, tomato, sweet potato etc. Globally, the pest has spread in Caribbean Island, Hawaii and French, Guianas, Indonesia, Sri Lanka, Thailand, USA, etc.



A cluster of *P. marginatus* on stem



Severely infested leaf



Severely infested stem and boll



Field infested with *P. marginatus*

7. Spherical mealybug *Nipaecoccus viridis* (Newstead)

Spherical mealybug *Nipaecoccus viridis* (Newstead) (Homoptera: Pseudococcidae) is an agricultural pest in Asia that attacks wide variety of plants that includes food, forage, ornamental crops and fiber crops especially cotton often causing considerable damage. It is native to Asia and widespread throughout the tropics and subtropics. The potential for invasiveness appears high. Cotton plants infested by mealybugs exhibit symptoms of distorted and bushy shoots, crinkled and/or twisted and bunchy leaves, and stunted plants that dry completely in severe cases causing reduced plant vigor and reduction in yield. In India the species has been recorded on cotton in parts of Andhra Pradesh, Delhi, Maharashtra and Orissa (Thomas and Ramamurthy, 2011) with negligible losses. The adults are about 4 mm long, body is round or broadly oval; somewhat flattened dorsoventrally; purple or blue green; covered by thick white/creamy/pale yellow wax. Females produce an ovisac with a wax that is sticky to touch.



Female *N. viridis*



N. viridis infested leaf



N. viridis infestation on stem



N. viridis affected patch in the field

8. Pink hibiscus mealybug *Maconellicoccus hirsutus* (Green)

Pink hibiscus mealybug *Maconellicoccus hirsutus* (Green) (Homoptera: Pseudococcidae), also known as the grape mealybug, is a pest of cultivated and uncultivated plants, trees, and shrubs. The pest has its presence in most tropical areas of the world, prominently in Asia, Africa and Australia. It infests crops such as hibiscus, citrus, coffee, guava, mango, soybean, cotton, maize etc. Infested plants show colonies of *M. hirsutus*, thereafter the colonies grow into large masses of white waxy coverings on branches, fruiting structures and even whole plants. Adult females are wingless measuring about 3-4mm long. Female body is pink in colour with white waxy coating. Males have a pair of wing and two long waxy tails. Female



Adult female of *M. hirsutus*



Infestation on branch by *M. hirsutus*



M. hirsutus infested plant



M. hirsutus infested boll

lays approximately 650 eggs which are initially orange in colour later on turn to pink on maturity. The species completes its life cycle in 23 to 30 days. It has several overlapping generations up to 15 in a year (Mani, 1989). It is sporadic pest of cotton occasionally recorded in central and south India.

9. Striped mealybug *Ferrisia virgata* (Cockerell)

Striped mealybug *Ferrisia virgata* (Cockerell) (Homoptera: Pseudococcidae) is known by several names viz. cotton scale, grey mealybug, guava mealybug, spotted mealybug, tailed coffee mealybug, tailed mealybug; white-tailed mealybug. *F. virgata* is highly polyphagous infesting over 150 genera in 68 families (CABI, 2002) distributed in more than 110 countries around world (DOCS, 2013). Female is



F. virgata female



F. virgata infestation on leaf



F. virgata infested leaf



F. virgata infested stem

yellow / green in colour measuring about 4-4.5 mm in length with two dark stripes stretched down to her length. The mealybug bears two long wax tails while waxy threads extend in all directions. It infests all plant parts and developing boll gets scarred due to desapping. Nymphal duration of female was 43.2 days at 28.9 °C and the total life span ranged between 76-154 days on potato sprouts (Awadallah *et al.*, 1979).

10. *Malvastrum* mealybug *Ferrisia malvastra* (McDaniel)

Malvastrum mealybug *Ferrisia malvastra* (McDaniel) is a widespread, polyphagous species first described from *Malvastrum* (Malvaceae) from Texas, U.S.A., but was confused with *F. virgata* for many years (SEL, 2013). Sometimes confused with *F. virgata* as phenotypically both species appear similar but former has a more rounded body (Ben-Dov 2005). Adult female of *F. malvastra* is oval bodied and yellowish in colour with waxy particles found on their bodies. The body measures about 3.5 mm long. Adult males are dipterous and brownish in colour. They have a pair of conspicuous white wings and two long waxy caudal filaments. Male longevity is 2-3 days. Female matured in 12-19 days while male in 14-21 days at 21-24 °C. The species reproduces sexually as well as ovoviviparously. A single female produces 467-507 nymphs. *F. malvastra* produces dieback, often resulting in death of the plant (Seni and Sahoo, 2012a)

11. Mango mealybug *Rastrococcus iceryoides* (Green)

Mango mealybug *Rastrococcus iceryoides* (Green) (Homoptera:



Adult female *R. iceryoides*



R. iceryoides infested leaves and branch



R. iceryoides infested stem



Infestation by *R. iceryoides*

Pseudococcidae) is a minor pest of cotton in central and south India found along with other mealybugs affecting cotton such as *P. solenopsis*, *P. marginatus* and *N. viridis*. This has been found to damage several hosts like custard apple, mango, guava, citrus, tea, drumstick, hibiscus, etc. Both nymph and adult suck the cell sap. On severe infestation leaves turn yellow, gradually dry and ultimately the plant gets defoliated. The species reproduce sexually as well as through oviparity. Only fertilized eggs are laid by females, average numbers/female were 450-585 (Rawat and Jakhmola, 1970). The female and male nymphs molted thrice and four times, respectively in 18-24 days and 16-22 days at 26-36 °C and 84-91 % RH to attain their adulthood. The pre-oviposition, oviposition period and incubation period of eggs were 6-11 days, 4-6.9 days and 5.2-7.6, days, respectively (Seni and Sahoo, 2012b). *R. iceryoides* is an invasive mealybug species that originated from south East-Asia and attained serious pest status on wide range of host plants.

12. Ber mealybug *Perissopneumon tamarindus* (Green)

Ber mealybug *Perissopneumon tamarindus* (Green) (Homoptera: Monophlebidae) was first reported from CICR experimental farm during crop season 2009-10 on cotton. Its presence was recorded on roadside trees and the adjoining cotton crop in Sirsa at four locations during 2010-11 and also 2011-12 without causing economic damage. Average maximum per cent incidence and mean population/ plant of *P. tamarindus* were 63.50 and 10.49 and lowest were 4.67 and 3.22, respectively at all the infested locations. A predatory bug *Rodolia fumida* (Mulsant) (Coleoptera:



P. tamarindus adult female



P. tamarindus congregation on leaf



P. tamarindus on cotton plant



P. tamarindus on Ber plant

Coccinellidae) associated with *P. tamarindus* was also recorded. This mealybug was observed on 50 hosts (16 trees, 2 fruit trees, 22 weeds, 6 ornamentals, 2 medicinal plants and 2 field crops) belonging to 21 families.

Mirids

Mirids occur on a wide variety of plants, while some are predators on small soft bodied insects and insect eggs. Mirids are in general yellow, green brown or black in colour, while some are colourful. Most of the well-known mirids have received attention because they are agricultural pests. *Creontiades biseratense* (Distant) has been found to be predominant in South India, *Campylomma livida* Reuter in all the three zones while *Hyalopeplus lineifer* Walker is common to both central and south regions (Udikeri, 2008). Nymphs and adults are observed to feed on squares and small developing bolls. During feeding, mirids pierce the plant tissues with their stylet. The affected area becomes dull in colour, then blackens and ultimately results in death of cells in the region. Feeding by these insects led to heavy shedding of medium sized squares and tiny bolls. Larger squares suffer damage that may cause development of deformed bolls which is often referred to as 'parrot beaking'. If the infestation is severe in older bolls, the damaged locules may not develop properly and often carry stained lint (Khan *et al.*, 2004). Nymphs and adults damage the squares, flowers and small tender bolls of cotton and affected parts gradually turn yellow, shrivel and drop down prematurely (Ravi and Patil, 2008). Mirids are very active, running and hopping with short rapid flights when disturbed. With introduction of Bt-cotton and subsequent reduction in insecticidal spray for the control of bollworm especially *H. armigera*, sucking pests like mirids which were controlled by the broad spectrum sprays, are now emerging pests on Bt cotton.

13. Indian cotton mirid *Creontiades biseratense* (Distant)

Indian cotton mirid *Creontiades biseratense* (Distant) (Hemiptera: Miridae) infestation was recorded in an epidemic form in Coimbatore on Bt-cotton hybrids during the month of December 2006 (Surulivelu and Dharajothi, 2006). Adult are brown in colour with dark brown T-shaped band on pronotum. Nymphs are greenish in colour with dark brown wing pads. The females preferred to lay eggs in petiole wherein upto 15 eggs were traced. A green colour morph is also available with similar taxonomic features. There are five instars in the life history extending total life cycle up to 39-41 days (Udikeri *et al.*, 2010). Both nymphs and adults damage developing flower buds and tender bolls. One to two day old bolls with dried petals intact provide a good habitat for the insect's feeding and sheltering. The characteristic symptoms of feeding on the flower bud are described as oozing out of yellow fluid from the buds and staining of this yellow fluid on the inner surface of the bracts. Infested tender bolls have number of black patches on all sides of the outer surface of boll rind and shedding of most of the damaged tender bolls is observed. Heavy shedding of squares and bolls which led to significant reduction in seed cotton yield of Bt cotton due to *C. biseratense* was observed from Karnataka (Patil *et al.*, 2006). During 2007 to 2009 mirid populations ranged from 18 to 66 bugs/ 25

squares and reached their peak at all locations in September and continued until December. High population of mirid bugs were recorded in Haveri (44 mirids/25 squares) and Belgaum district (43.8 mirids/25 squares). However, in Gulbarga the population was found to be low (18 mirids/25 squares). The severity of mirid incidence has been also noticed in Raichur and Bellary districts, however in Bidar, Bijapur, Gadag, Mandya and Uttar Kannada its incidence was low to moderate. None the less irrespective of the cultivar it was regularly noticed. The estimated loss due to this pest was 449 kg/ha (Udikeri *et al.*, 2011). Eleven species of plants have been recorded as alternate hosts of *C. biseratense* (Ravi and Patil, 2008).



Adult *C. biseratense*



Nymph *C. biseratense*

14. Mirid *Campylomma livida* Reuter

Adult *Campylomma livida* Reuter (Hemiptera: Miridae) measures about 2-3 mm in length and causes significant damage to squares and bolls in all the three cotton growing zones of India. In central India the pest has been recorded since 2001 although its identity was confirmed in 2005. Adults of *C. livida* are flat, green, straw yellow or brown coloured, 2-3mm long and 1-2mm wide with long and slender antennae, and have an oval body outline with a conspicuous greenish or yellowish triangle in the centre of the back. Nymphs and adults feed on the terminal growth, squares, flowers and bolls of cotton plants with their piercing/sucking mouthparts and thus cause excessive shedding of flowers, small squares and immature bolls. Developing bolls usually do not shed, but may have one or more locules damaged. Mirids occur throughout the season on cotton with maximum population



Adult *C. livida*



Nymph *C. livida*



Damage to flower by *C. livida*



Parrot beaked bolls due to *C. livida* damage

development between 50 and 90 days of crop age. *C. livida* feeding on pre fruiting plants causes abortion of plant terminals, resulting in many branched plants (Vennila *et al.*, 2012). When small to medium sized squares are fed, drying and abscission of squares occur within 3-4 days. Feeding by *C. livida* on green bolls resulted in reduction in the weight of seed cotton by one gram per boll. Amongst different sample sizes; maximum *C. livida* population was recorded in sample size of 15 plants. Since mirid adults are highly mobile, counting nymphal and adult population together from top-one third plant canopy with sample size of 15 plants per acre was found to be appropriate.

15. Mirid *Hyalopeplus lineifer* Walker

Mirid *Hyalopeplus lineifer* Walker (Hemiptera: Miridae) was found to occur on cotton in central and south India. Presence of brownish parallel streaks on the pronotum is the distinct identifying character of the species. Diverse colour morphs have been noticed by *H. lineifer*. Nymphs of this species are creamish yellow in colour with long antenna and wing pad. Both nymphs and adults of *H. lineifer* were observed to feed on squares and small developing bolls. They pierce the stylet in plant tissues while feeding. The affected area rapidly turn dull in colour, then blackens and ultimately results in death of the cells in the region. Feeding by these insects results in heavy shedding of medium sized squares and tiny bolls. As the squares and bolls drop off, significant reduction in yield is noticed.



Adult *Hyalopeplus lineifer*



H. lineifer Nymph feeding on squares

16. T Mosquito bug *Helopeltis bradyi* Waterhouse

T Mosquito bug, *Helopeltis bradyi* Waterhouse (Hemiptera: Miridae) also referred as Kajji bug is a pest of cashew, guava and tea. However, it has been recorded as an emerging pest causing economic damage in Bt cotton in close proximity to Dharwad and Uttar Kannada districts of Karnataka during 2009. T mosquito bug outbreak was noticed in DCH-32 interspecific hybrid grown in HD Kote taluk of Mysore district (Karnataka) during 2002. Though it appeared occasionally, the losses were more than 90 per cent. The adults of the species are light brown in colour. Both nymph and adults of the species suck cell sap from foliage, squares and bolls. Due to sucking of sap from phloem, leaves get rolled at the edge with brown central black lesions particularly near the main veins. Cankers develop on the lower green bolls. Linear scars with white papery layer appear in tender shoots. The affected plant's growth retards and lead to subsequent gradual dying of shoots. Matured bolls bear blackish brown circular pits towards tip of the bolls. Rotting of bolls takes place due to entry of rainwater and such infested and dried up bolls/ squares remain intact on plant (Udikeri *et al.*, 2011). Damage on the boll rind is seen as raised dry dark brown callus like structures on the outside. It also causes bad opening of bolls and makes the lint unfit for use. The pest is distributed in. Bangladesh, India (Karnataka, Kerala, Tamil Nadu), Indonesia, Java, Sumatra, Timor, Malaysia, Sabah, Singapore, Sri Lanka and Vietnam and is reported to attack cocoa, cashew, cinchona, tea etc. (CABI 2013c). Female lays about 140 eggs. The insect completes its development in 5 instars in about 9 days. Adult male lived shorter, for about 24 days as compared to 26 days of the female (Srikumar and Bhat, 2012).



Adult *H. bradyi*



Canker on boll by *H. bradyi*



Fully damaged boll by *H. bradyi*



Thickening and twisting of stem by *H. bradyi*

Cotton bollworms

1. American bollworm *Helicoverpa armigera* (Hubner)

American bollworm, *Helicoverpa armigera* (Hubner) (Lepidoptera: Noctuidae) also called legume pod borer, cotton bollworm, tomato fruit-worm, is a major pest of cotton and one of the most polyphagous and widespread species in central and southern Europe, Asia, Africa, Australia Oceania and very recently in Brazil. The pest feeds on a wide range of plants of about 182 species, including many important cultivated crops especially tomato, cotton, pigeon pea, chickpea, sorghum and cowpea (Gowda, 2005). In pre Bt era *H. armigera* exhibited widespread resistance to Pyrethroids (Cypermethrin) varying between 23–8022 fold (Kranthi *et al.*, 2002).

The larvae feed on the leaves initially and then bore into squares / bolls and seed with their head thrust into the boll, leaving the rest of the body outside. Excreta surrounds the entry hole. Damaged squares flare up, have feeding or damage holes on them and are shed. Clear-cut round feeding holes on squares and bolls with or without larvae are seen. Larvae show preference for feeding on squares and flowers when present, however they feed on young bolls too. A single larva can damage 30-40 fruiting forms during its developmental period. The entry holes are large and circular at the base of the boll. Feeding on bolls can be extensive. Larval damage attracts boll rot microbes, and damaged bolls rot resulting in yield loss up to 40 % in non Bt cotton. Period of onset varies with the season but period of damage can extend into November-December.



'Flared up' damaged square by ABW larva



Typical larval feeding habit of ABW larva



Boll contents destroyed by ABW larvae



Adult moth ABW

Adult moths are stout bodied, greenish yellow to buff brown with darker brown or blackish markings. Males are light brown with greenish hue. Females are darker than males. Moth length varies between 12-20 mm with a wingspan of 30–40 mm. They have a circadian rhythm formatting starting at dusk, continues through midnight after which it virtually ceases. Moths disperse over long distance in search of suitable crops from source host. Female lays up to 700 eggs during adult life of 8-12 days and life cycle is completed in 25-60 days. First and second generations are found on several crops and weed hosts. Second generation usually infest cotton in low numbers (Vennila *et al.*, 2007d). Population increases dramatically during third and fourth generation with major outbreak coinciding with peak squaring of the first and rarely affecting the second flush on non Bt cotton. In the nineties incidence of *H. armigera* coincided with the active monsoon period in India, thus making control almost impossible, especially in epidemic years.

H. armigera infestation reduced significantly in the last decade and it rarely exceeded economic threshold levels in majority of the cotton growing regions of India. The obvious reasons were introduction of Bt-cotton, change in insecticide use pattern, decrease in pyrethroid use, increase in the use of new chemistries and large scale implementation of IRM/ IPM (Kranthi and Russell, 2009). In the 2012 crop season *H. armigera* was found to infest non Bt cotton, cultivated under HDPS with straight hirsutum varieties crossing ETLs in many demonstration fields in the Vidarbha region. Incidence of this pest on HDPS cotton will necessarily have to be managed with effective IPM until Bt varieties are available commercially.

2. Spotted bollworms *Earias insulana* (Boisduvel), *E. vittella* (Fab.)

Spotted bollworm *Earias vittella* (Fabricius) (Lepidoptera: Noctuidae) is found to infest crops like cotton, okra, *Abutilon indicum*, hibiscus, and several other hosts. *E. vittella* is seen in south and central India while *E. insulana* is predominant species in north India, on cotton. *Earias insulana*, commonly known as spiny bollworm, also occurs with *E. vittella* and causes similar damage and the adults can be distinguished from *E. vittella* by their fully green forewings.

E. vittella incidence commences as early as on 3 weeks old crop. The damage due to *Earias* to fruiting bodies of age 15-16 weeks is high whenever *H. armigera* incidence is low to moderate. Nevertheless beyond 20 weeks after crop emergence damage by *Earias* is continuous. Terminal shoot dry and wither away when the larvae bore into the pre-squaring plants. The main stem collapses, if the growing point is affected. Feeding holes in squares and on bolls are seen with or without larvae. Flare up of squares and their shedding, premature dropping or opening of attacked bolls are common. Larvae do not confine their feeding to a single boll and hence damage is not proportionate to their numbers. Damaged bolls often succumb to secondary infection by bacterial and fungal pathogens. *E. vitella* mean damage in rainfed cotton production system can reach >10%. Earlier spotted bollworm was a pest dominant on *G. arboreum* in India. With the introduction of upland cotton the pest was found to damage upland cotton too. Presently this pest continues to be recorded in higher numbers on desi varieties.

The two species have differential identification characters. Head, thorax and forewing colour of *E. insulana* vary from silver green to straw yellow while *E vittella* moths are creamy white or peach with a central green wedge running from proximal to the distal edge of the forewing. The wing span of moth is about 20-22 mm, full grown larvae are 13-18cm. Moth lays 2-3 eggs on bracts, leaf axils, veins on the under surface of leaf, single female lay up to 385 eggs, total life cycle ranges from 20-22 days (Vennila *et al.*, 2007e). *E. vitella* is distributed in Asia, Australia, Pacific islands and Africa.



Apical shoot damage by SBW larvae



Square damage by SBW



Boll damage by SBW



Adult moth of SBW

3. Pink bollworm *Pectinophora gossypiella* (Saunders)

Pink bollworm *Pectinophora gossypiella* (Saunders) (Lepidoptera: Gelechiidae) is native to Asia, has become economically destructive pest of cotton in South America, Africa, Asia, Australia, Pakistan, Egypt, USA and Mexico. All the four cultivated species of cotton (*Gossypium hirsutum*, *G. barbadense*, *G. herbaceum*, *G. arboreum*), okra, country mallow, *Hibiscus*, sorrel, lucerne are the primary hosts. In India, pink bollworm is functionally monophagous.

Pink bollworm generally occurs at 90 DAS and beyond. Larvae initially feed on the flower buds that results in failure of bud opening and shedding. Larva enters into the developing boll through the rind feed on developing cotton seeds. In younger bolls entire content can be destroyed, in older bolls larvae feed up to 3–4 seeds. Within a boll more than one larva can be seen. 'Rosetted flower' is the typical symptom of pink bollworm infestation. Small exit holes are seen on the developing bolls. Quality

of lint deteriorates due to the presence of larvae and lint gets stained by the pest. *P.gossypiella* is known to cause 2.8 to 61.9 per cent loss in seed cotton yield, 2.1 to 47.10 per cent loss in oil content and 10.70 to 59.20 per cent loss in normal opening of bolls (Patil, 2003). Resistance levels of 23–57-fold to endosulfan were recorded in some areas of Central India (Kranthi *et al.*, 2002).

P.gossypiella lay eggs singly or in groups of four to five. Eggs are pearly white, flattened, oval about 0.5mm in length and 0.25 mm wide. Larvae are white in colour in first two instars, later instars are pink in colour. The larvae have characteristic dark brown head. Pupae are dark brown measure about 7mm in length. The adult moth is greyish brown with blackish bands on forewings while hind wings are silvery grey. Moths are nocturnal in habit, hides in soil debris during day time. Larvae can be sexed two spots on the ventral side indicate that the larvae is a female while males do not have the spots.

In the recent past, pink bollworm attained national importance and received wide news coverage (The Hindu, 6th March 2010) indicating Bollgard (containing *cry1Ac*) failed to protect cotton crop from this pest in certain parts of Gujarat. Dhurua and Gujar (2011) observed field-evolved resistance of pink bollworm to *cry1Ac* in the population collected during 2007–2008 and 2008–2009 seasons from non-*Bt* cotton fields in Amreli district of Gujarat. On investigation it was observed that Bollgard provides sufficient protection against the pest (Mohan and Nandini, 2011).

Pink bollworm feeds on non Bt seeds that is available in the segregating seeds of the



Peculiar damage by PBW



Larvae of PBW in loculi of green boll



Cotton damaged by PBW



Adult moth of PBW

F₁ bolls of single gene Bt hybrid. Thus, it is not unusual to record survival PBW larvae on Bt cotton. Extended Bt cotton in parts of Maharashtra (Jalna, Jajgaon, Nanded) also record the incidence of PBW larvae.

For sampling, 20 green bolls can be taken to assess the pest situation. Pheromone trapped moths are good indicators for the initiation of pest control in non Bt cotton. Trap catches of more than 8 moths/trap/night over 3 consecutive nights forms the ETL. In Bt-cotton pheromone trap catches do not correlate with damage.

Other insects

1. Tobacco caterpillar *Spodoptera litura* Fabricius

Tobacco caterpillar, *Spodoptera litura* Fabricius (Lepidoptera: Noctuidae) also known as oriental leafworm, cluster caterpillar, cotton leafworm, tobacco cutworm and tropical armyworm. It is found mainly in the Indo-Australian tropics but has now established on most Polynesian islands. The larva feed on a wide range of plants and has been recorded from over 40 mostly dicotyledonous plant families. During late nineties, *S. litura* exhibited high resistance levels of 61-148 fold to cypermethrin, while resistance was 45-129 fold to chlorpyrifos in south India (Kranthi *et al.*, 2002).

Larvae attack the crop in large numbers and are damaging and gregarious in nature. Bt cotton harboring *cry1Ac* gene does not offer protection against this lepidopteran pest as *Spodoptera* larvae do not have receptor sites for the binding of *cry1Ac*



Eggs of *S. litura* in a clump



Gregarious feeding habit of *S. litura*



Larva *S. litura*



Adult moth of *S. litura*

(Lalitha *et al.*, 2012). Bollgard II that harbors the *cry1Ac* and *cry2Ab* genes is moderately effective against *Spodoptera*. Two species occur on cotton in India- *S. litura* and *S. exigua* and intra-specific variation exists in their tolerance to cry toxins (S. Kranthi, Unpublished) with *S. exigua* being more susceptible as compared to *S. litura*.

Spodoptera larvae hatch from eggs laid in masses. The larvae feed by scraping the leaves leaving behind the veins and veinlets. *Spodoptera* are nocturnal and can cause extensive damage to the cotton crop. Pheromone monitoring methods that are often recommended demonstrates no correlation between the numbers of moths trapped to larval incidence in the field. Scouting for egg masses is the best method for detection and their destruction for management. Economic threshold levels for *S. litura* on Bt and non Bt cotton were 12 and 4 larvae/plant, respectively under rainfed conditions.

2. Cotton Semilooper *Anomis flava* Fabricius

Cotton semilooper, *Anomis flava* Fabricius (Lepidoptera: Noctuidae) is found in large parts of the world, including India, China, Hawaii, Thailand and Australia. The larvae feed on upland cotton, *Hibiscus rosa-sinensis*, *Hibiscus cannabinus* and *Legnephora moorei*. The caterpillar is long and green, with yellowish bands between segments. One pair of prolegs is missing, so it moves like a semilooper. Sexual dimorphism is recorded in adults in the colour of the wings and antennal structure.

A. flava occurs during peak vegetative stage of the cotton crop. It is common in central India often found feeding on the leaf lamina causing holes in fully expanded tender leaves during peak vegetative phase. More than one caterpillar can be found on a plant. Overlapping generations are seen during the season with caterpillars of different sizes being recorded at a given point of time. Semilooper infested plants look unhealthy and stressed especially under bright sunlight and high temperature during the day. Bt-cotton is highly tolerant to semilooper damage. These caterpillars do not contribute to significant economic loss on non Bt cotton. Instead they serve as natural biofactories in the field allowing the multiplication of parasitoids, especially larval parasitoids (such as *Apanteles*) and entomopathogenic fungi (especially *Beauveria* and *Metarrhizium*). It is advisable to discourage application of insecticides during 45-60 DAS especially in central India.



Larvae of semilooper



Semilooper adult

3. Cotton leaf folder *Sylepta derogata* (Fabricius)

The cotton leaf folder, *Sylepta derogata* Fabricius (Lepidoptera: Crambidae) is a minor pest of cotton as it occurs in October- November at the reproductive stage and does not appear consistently year after year. The leaf folder and semilooper do not survive on Bt cotton as they are very sensitive to *cry1Ac*. Hence it is common to see leaf folder symptoms in the non Bt cotton if sown as refuge around Bt cotton. Leaf folder population serves as a natural enemy repository in the field. However, its incidence does not synchronize or precede the incidence of bollworms. The pest is distributed in India, Bangladesh and Pakistan. It is polyphagous and attacks agricultural crops and forest plants apart from several bamboo species. The moth is pale yellow in colour. The eggs are laid in rolled leaf cases. On hatching larvae feed gregariously on the rolled leaf and subsequently migrate to form its own roll. The life cycle ranges from 23 to 45 days.

Leaf folder damage appears in the form of leaves turning into funnel shaped structures and each funnel harbors one to few leaf folder larvae, feeding within, scraping on the leaf lamina. Larvae are often enclosed in soft silken web and are surrounded by frass. Leaf folders rarely cause economic losses in cotton and do not require any intervention for management.



Larva and fecal pellets in a leaf roll



Typical leaf folder symptoms, pupa rest on damaged leaf



Leaf folder damage on cotton plant



Leaf folder moth

4. Safflower caterpillar *Condica capensis* (Guenee)

Safflower caterpillar *Condica capensis* (Guenee) (Lepidoptera: Noctuidae) was found to feed on Bt cotton leaves in Hingoli and Buldhana districts of Maharashtra.

C. capensis seen along with *Spodoptera* in cotton field in the early vegetative stage, adjoining soybean field. However, larvae did not feed significantly on Bt cotton leaves in the laboratory as neonates died at the end of 7 days. Larvae survived on non Bt cotton leaves but neonates gained poor weight. Adult female moths had a pre-oviposition period of 3 days, egg period of 3-5 days, larval period of 14-17 days and a pupal period of 5 days. Full grown larva can be confused with *H. armigera*. Chemical sprays need not be used for their management on Bt cotton.

The adults are stout, forewings are brown with a pair of eye-like marks in the centre. Eggs are small, spherical and golden in colour laid on the leaves in clusters and are covered by hair, like that of *Spodoptera*. A full grown caterpillar is large about 25mm in length. The pupation takes place in soil. The pest is distributed in India, Pakistan and South-East Asia.



Adult *C. capensis*



Fifth instar larva of *C. capensis*

5. Stem Weevil *Pempherulus affinis* (Faust)

Stem weevil *Pempherulus affinis* (Faust) (Coleoptera: Curculionidae) is an endemic pest to some parts of south India, particularly Tamil Nadu. It is not a serious menace in regular season crop and causes less than 10% mortality of plants. Off season crop (i.e., Winter season crop in the summer cotton tract) was much affected compared to the regular season crop (i.e., Summer season crop in the summer cotton tract) (Murugesan *et al* 2010). Adults are very small weevils, dark in colour with two small white patches on the elytra. Grubs are white in colour and apodous. By feeding, the grub forms a tunnel like passage inside the stem leaving the outer



Adult *P. affinis*



Weevil damaged plant

bark intact. The grub cuts through the medullary rays, tunnels round the stem along the cambium causing spiral galleries which damages the vascular tissues, disrupting transport of plant nutrients. Young plants are killed in cases of serious infestation; however, mature plants survive with reduced vigor by developing a woody shoot axis gall at the collar region of the plant. Galls are the weak point of the plant and is regular, localized, globular, oval or fusiform and extensively nodulated. Infested plant gets killed in course of time either due to blockage of plant nutrients; break down at the gall region due to strong winds, intercultural operations or excessive boll load at later stage. The weevil is found to occur only in the irrigated crops where high requirements of moisture are met (Krishna Ayyar and Margabandhu, 1941). Though, it is mainly a pest of cotton, however other host plants such as okra, *Hibiscus cannabinus*, *Thespesia populnea* and *Triumfetta* sp. are known to be attacked

6. Flower bud maggot *Dasineura gossypii* Fletcher

Flower bud maggot or gall midge of cotton *Dasineura gossypii* Fletcher (Diptera: Cecidomyiidae) was reported to cause severe damage during August to the cotton crop sown in the month of June in Haveri district of Karnataka during 2009. It was also seen in minor proportion in Raichur, Bellary, Belgaum, Gulbarga and Dharwad districts and is endemic to Karnataka. The maggots are the damaging stage feed on anthers and staminal column leading to degradation or decaying. About 3-15 maggots have been seen in a flower bud. The infested flower buds fail to grow



Adult Flower bud maggot *D. gossypii*



Deformity in bolls by *D. gossypii* damage



D. gossypii maggot feeding on flower



D. gossypii pupae on bracts

normally and are unable to open as the petals as well as tissue inside dries. Subsequently flower dies due to degradation of flower organs. Squares do not develop into bolls. Drying of tissue or death of flower leads to twisted or contorted staminal column/ anthers. Tender bolls demonstrate the presence of small hole exposing necrotic tissue within. Presence of pink or whitish coloured maggots are seen when the bolls are cut open. The bolls do not reach to normal size and are characterized by abnormal fibre development. Fly pupate inside the dried flowers (Udikeri 2011). Historically, the pest was reported from Coimbatore (Tamil Nadu) as a pest of cotton referred to as floral bud maggot (Ayyar, 1932).

7. Red cotton bug *Dysdercus cingulatus* Fab.

Red cotton bug *Dysdercus cingulatus* Fab. (Hemiptera: Pyrrhocoridae) is found to infest cotton in all cotton growing regions spreading in Asia, Africa, USA and South America. During off season it survives on *Hibiscus* spp., okra, Abutilon, etc. Both adults and nymphs suck the sap from leaves, green bolls and seeds of partially opened bolls. Affected bolls opened defectively and their lint is stained with the excreta or body juices. Quality of the lint is affected and the attacked seeds become unfit for sowing or oil extraction. Secondary infection due to bacteria results in rotting of the entire content followed by discolouration of the lint to yellow or brown. Stained or discoloured lint turns to typical yellow colour. Reddish nymphs are seen in aggregation around developing and open bolls. Adult movement on the soil and over the plant is commonly seen once the infestation initiate in cotton fields.

Red cotton bug infestation starts in 16th week after sowing in Bt-cotton and a week later in non Bt-cotton. The maximum infestation 45.33% was recorded in 28th week of Bt-cotton crop, 37.33% in 27th week of the non Bt-cotton. The overall infested plants ranged from 5 to 40% in Bt-cotton while 1 to 31% in non Bt-cotton during October to March (Sammaiah *et al.*, 2012).

Red cotton bug adults measure about 12-13 mm in length and have deep red legs and antenna. Forewings bear black spots. About 100-130 eggs are laid under the soil in cracks and covered with loose soil with dry leaves. Nymphs are wingless and pass through five molts. The development is completed in 50-90 days (Vennila *et al.*, 2007f).



Adult *D. cingulatus*



Opened boll infested by nymph *D. cingulatus*

8. Dusky cotton bug *Oxycarenus hyalinipennis* (Costa)

Dusky cotton bug *Oxycarenus hyalinipennis* (Costa) (Hemiptera: Oxycarenidae) is known as *Bhurke dhekun* (in Marathi), suck the sap gregariously from immature seeds thereby affecting their development and maturity, remain light weight, discoloured with severe shrinking and seed germination is severely affected. Adults found in lint get crushed during ginning, emitting bad odor while staining the lint. They cause irritation to workers during cotton picking. Discolouration of lint by large number of nymphs and adults of brown to black colour are common. The pest attacks mainly on cotton while malvaceous crops like okra, *Sterculia* spp. and *Ceiba* sp. are alternate hosts. The infestation of *O. hyalinipennis* started in the 17th week on Bt and non Bt-cotton and reaches peak infestation of 46.33% in Bt-cotton and 38% in non Bt-cotton in 29th week. The infestation ranged from 2 to 41% in Bt-cotton and 2 to 35% in non Bt-cotton (Sammaiah *et al.*, 2012).

Dusky cotton bug adults measure about 4-5mm long with pointed heads, dusky brown with dirty white transparent wings and black spots on fore wings with deep red legs. The eggs are laid singly or in small groups loose amongst the seeds in the open boll. Each female lays around 25-40 eggs. Egg and nymphal period lasts for 7 and 26 days respectively. The development is completed in 40-50 days.



Adult *O. hyalinipennis*



O. hyalinipennis infestation

9. Green weevil *Tanymecus princeps* Faust

Green weevil *Tanymecus princeps* Faust (Coleoptera: Curculionidae) was recorded infesting non-Bt cotton during off-season at CICR, Nagpur. It was found feeding on



Adult *T. princeps*



T. princeps infestation

cotton leaves. The weevil is green in colour measuring about 10-12 mm in length and 5mm in width. The weevil is distributed in West Bengal, Gujarat, and Karnataka.

10. Cotton grey weevil, *Myloccerus maculosus* Desb.

Cotton grey weevil *Myloccerus maculosus* Desb. (Coleoptera: Curculionidae) is a minor pest of cotton, adults are grey in colour while grubs are white and legless. The pest remains active in cotton from April to October–November. Adults feed on leaves, buds and flowers while grubs feed on the roots. Besides cotton, it feeds on some of the host plants like bajra, maize, sorghum, guava, pigeon pea and groundnut.



Adult *M. maculosus*



Damage by *M. maculosus*

Biological control agents

In nature, various biological control agents such as predators, parasitoids/parasites, entomopathogens like bacteria, viruses, fungi, nematodes etc. offer natural control of pest at varying degrees and play a pivotal role in regulating pest population. In cotton ecosystem, different groups of biological control agents are common. A rich fauna of naturally occurring bioagents have been reported on insect pests of cotton crop. India is very rich in biodiversity of biocontrol agents. From cotton alone 106 species of spiders, 450 species of coccinellids, 60 species of chrysopids and 26 species each of trichogrammatids and anthocorid bugs have been recorded from India (Singh, 2001 & 2003). Presence of predators and their predation can be noted visually, the occurrence of parasitoids could only be realized by observing the activity of adult parasitoids within the specified area and more authentically by rearing the host insects collected from the field in the laboratory. Nevertheless a biological control agent offers significant natural control of cotton pests. Role of predators, parasitoids, hyperparasitoids and entomopathogens is summarized below.

Predators

1. Lady bird beetle *Cheilomenes sexmaculata* (Fabricius)

Lady bird beetle, *Cheilomenes sexmaculata* (Fabricius) (Coleoptera: Coccinellidae) also commonly known as six-spotted zigzag ladybird, is a general predator of cotton

whiteflies, mealybugs, leafhoppers, mites, and early instar lepidopteran larvae. The predator is distributed throughout India, Iran and Australia. Grubs and adults are predatory. Besides cotton, this beetle occurs on sunhemp, maize, sorghum, rice, finger millet, cowpea, okra, egg plant, cabbage, cauliflower, groundnut, lucerne and several other plants. The beetle is active throughout the year in several parts of India with several generations. Among the different insecticides tested, Buprofezin was found to be the safest insecticide, to all the stages (eggs, larvae, pupae and adults) of *C. sexmaculata* and pupae were found to be more resistant to the insecticides as compared to the eggs (Aggarwal and Neetan, 2011).

The beetle population can be limited by Hymenopterans-*Dinocampus coccinellae* (Schrank); *Nothoserphus mirabilis* Brues; *Homalotylus eytelweini* Ratzeburg, *Homalotylus flaminus* (Dalman), *Homalotylus terminalis* (Say); *Oomyzus scaposus* (Thomson) *Pediobius foveolatus* (Crawford), *Tetrastichus sexmaculatus* Kurian, *Tetrastichus* sp.; Hemipterans-*Eocanthecona furcellata* (Wolff)); Acari-*Coccipolipus* sp.; Nematode-*Parasitylenchus coccinellae* Ipert & Waerebeke; Bacteria-*Wolbachia* sp. (NBAIL, 2013a).



Adult *C. sexmaculata*



Grub *C. sexmaculata* feeding on aphids

2. Lady bird beetle *Cryptolaemus montrouzieri* (Mulsant)

The Lady bird beetle, *Cryptolaemus montrouzieri* (Coleoptera: Coccinellidae), commonly known as mealybug destroyer is one of the most commonly used bio-control agents in various parts of the globe. Both larvae and adults feed on aphids, mealybugs, scales, mites and other soft bodied insects (Bozsis, 2006; Jalali *et al.*, 2009) infesting many horticultural and plantation crops such as citrus, coffee, ornamental plants, mulberry, egg plant, guava, mango, grapevine, sapota, etc.

C. montrouzieri is the first natural enemy deliberately introduced into India first in 1898 on the Nilgiri Hills to control *Coccus viridis* and other mealybugs on coffee (Mayne, 1953) but it could not establish then. However, it was rediscovered in 1951, since then, it has become a common predator of mealybugs and soft scales infesting several horticultural and plantation crops and ornamental plants in southern part of India. They are voracious predators of mealybug in nymphal as well as adult stages. Historically, it has played a major role in the natural control of different sucking pests, especially mealybugs (Mani, 1990; Mani and Krishnamoorthy, 2008).

The beetle has been mass reared and marketed into more than 40 countries (Malaise and Ravensberg, 1992). Adult *C. montrouzieri* consumed 98.59 first instar, 45.85 second instar and 10.15 third instar nymphs of *P. solenopsis* (Rashid *et al.*, 2012). For suppressing population of mealybug *P. solenopsis* on cotton, the beetle can be released on weeds and perennial trees prior to the cotton season and during the season on infested cotton plants. The beetle can be multiplied directly on the mealybugs cultured on the sprouted potato. Traditionally the beetle is multiplied by offering feed of *M. hirsutus* reared on pumpkin. Under field conditions, the population of beetle can be limited by Hymenopteran parasitoids *Cowperia indica* (Kerrich), *Homalotylus flaminus* (Dalman); *Pseudocatolaccus* sp.; *Spilochalcis porteri*. and predators Chrysopids, carabids and ants.



adult *C.montrouzieri*



Grub *C.montrouzieri*

3. Lady bird beetle *Scymnus coccivora* Ayyar

Lady bird beetle *Scymnus coccivora* Ayyar, (Coleoptera: Coccinellidae) are small insects. They are widely distributed in all cotton growing regions of India, Pakistan, Sri Lanka, Thailand, Malaysia and Papua New Guinea. Grubs and adults are predators of soft bodied insects viz., whiteflies, aphids, mealybugs, scale insects and mites. These are common on mealybug and aphid infestations on egg plant, cotton, guava, mango, mulberry, teak, citrus, grapevine, karanj, neem, etc.

4. Lady bird beetle *Nephus regularis* (Sicard)

Lady bird beetle *Nephus regularis* (Sicard) (Coleoptera: Coccinellidae) measuring



Scymnus coccivora



Nephus regularis

about 1.6-1.8 mm in length and 1.2-1.4 mm width feed on whiteflies, aphids and several mealybugs species including *C. insolita*, *F. virgata*, *M. hirsutus*, *N. filamentosus*, *P. minor* etc. It is widespread in India (Andhra Pradesh; Assam; Karnataka; Madhya Pradesh) and Pakistan (NBAII, 2013b). The beetle was also found to prey on *P. solenopsis* and *P. marginatus*. Rawat and Modi (1969) recorded the beetle on *F. virgata* in Madhya Pradesh.

5. Lace wings *Chrysoperla carnea* (Stephans)

Lace wings, *Chrysoperla carnea* (Stephans) (Neuroptera : Chrysopidae) also known as the common green lacewing, larvae are active predators and feed on several species of small bodied insects especially aphids, mites, thrips, whiteflies, eggs of leafhoppers, etc while adults feed on nectar, pollen and aphid honeydew. It is widely used in biological control of insect pests on crops. *C. carnea* is distributed in many parts of Asia, America and Europe. Populations of *Chrysoperla* (*carnea*-group) collected from cotton ecosystem from all over India were morphologically and acoustically characterized as *Chrysoperla zastrowi arabica* Henry *et al.* (NAIP, 2012). Under free choice, the first, second and third instar larvae of *C. carnea* consumed 28.28, 33.19 and 28.80 first instar nymphs of mealybug *P. solenopsis* (Rashid *et al.*, 2012). The predator has been found to be effective at controlling cotton whitefly, *Bemisia tabaci* in cotton crops (Kareim, 1998). The presence of larvae on the foliage was found to inhibit visitation and oviposition by *B. tabaci* which suggests the larvae may produce volatile semiochemicals which repels the whitefly (Bellows & Fisher, 1999).



Adult *C. carnea*



Grub *C. carnea* feeding on mealybugs

6. Hover fly *Eupeodes confrater* (Wiedemann)

Maggots of hover fly, *Eupeodes confrater* (Wiedemann) (Diptera: Syrphidae) feed on aphids while adults are known as pollinators. *E. confrater* is widely distributed in Asian countries India, Sri Lanka, Pakistan, China and Afghanistan. Aphids on cotton, wheat, mustard, cabbage, pomegranate and chrysanthemum are the preferred hosts of *E. Confrater* (Ghorpade, 1981). The adult female locates the aphid colonies and lays eggs ensuring that hatched larvae get sufficient feed. The adults remain active all the year round and the larvae grow up eating only aphids.



E. confrater maggot feeding on aphids



Adult *E. confrater*

7. Spiders

Spiders (Arachnida) are among the most abundant predators, play an important role as stabilizing agents or regulators of insect populations in agro, forest and other terrestrial ecosystems. Their presence in an ecosystem can influence the population dynamics of other arthropods. Spiders are the generalist predators, can kill a large number of insects per unit time and hence are of great importance in reducing and even in preventing outbreaks of insect pests in agriculture (Sunderland *et al.*, 1986). Both nymphs and adults are predatory on host insect leafhoppers, aphids, mirids, whiteflies and all lepidopteran larvae feeding on cotton leaves, bolls and squares. In cotton agro ecosystem wide range of spiders are found



Neoscona theisi (Walckenaer)



Oxyopes pankaji Gajbe & Gajbe



Thomisus spectabilis Doleschall



Thyene imperialis (Rossi)

which act as biological control agents of cotton insect pests among them four species viz., *Peuceitia viridana* (Stoliczka), *Oxyopes birmanicus* (Thorell), *Oxyopes salticus* (Hentz) and *Peuceitia latikae* (Tikader) were found to predominate in the cotton fields (Jeyaparvathi *et al.*, 2013). About 9 species of spiders were identified from cotton fields during crop season 2013-14.

8. Predatory stink bug, *Eocanthocona furcellata* (Wolff)

Predatory stink bug, *Eocanthocona furcellata* (Wolff) (Hemiptera: Pentatomidae) is a generalist predator. Nymphs and adults feeds on larvae of lepidoptera, coleoptera and hemiptera. It is distributed in India, Myanmar, Thailand, Indonesia, China, Taiwan, Japan and Okinawa. The nymphs are black with red markings on their abdomen and prothorax and a reddish proboscis while adults are black or dark-grey in colour with white and grey spots all over their prothorax and hemelytra. A female adult can consume about 4.5 caterpillars per day. Their predatory rates increase with prey density. The bug has been found feeding on the immature stages of the Mexican beetle, *Zygogramma bicolorata* Pallister, reducing its efficacy in the field.

9. Dipteran fly *Cacoxenus perspicax* (Knab)

Dipteran fly *Cacoxenus perspicax* (Knab) (Diptera: Drosophilidae) have yellow head and prominent orange-red eyes. This is a commonly collected predator of mealybugs. It is widely distributed in India, Sri Lanka, Australia, Nigeria, Congo, Gabon and several African countries. It predate on several mealybugs like *Maconellicoccus hirsutus* (Green), *Planococcus lilacinus* (Risso), *Nipaecoccus viridis* (Newstead), *Rastrococcus iceryoides* (Green), *Saccharicoccus sacchari* (Cockerell), etc. infesting cotton, sugarcane, pomegranate, citrus, guava, mango, etc.



Adult *E. furcellata* feeding on ABW larva



Adult *C. perspicax*

10. Apefly *Spalgis epius* (Westwood)

Lepidopteran predator, Apefly, *Spalgis epius* (Westwood) (Lepidoptera: Lycaenidae) is a well known butterfly feeding on various species of Pseudococcidae found in India such as *Coccidohystrix insolita* (Green), *Rastrococcus iceryoides* (Green), *Planococcus lilacinus* (Cockerell), and *Planococcus citri* (Risso), and also aphids. *S. epius* was also found to feed efficiently on the ovisacs, nymphs and adult of papaya mealybug *P. marginatus* infesting cotton and other hosts. Newly hatched

larvae of *S. epius* are pale pink in colour and remain inside the mealybug ovisac devouring the eggs of the mealybug. Natural occurrence of *S. epius* was recorded on *P. marginatus* on cotton in Tamil Nadu. Among the 3 stages of the predator larvae, 3rd instar larva consumes maximum number of crawlers followed by 4th instar larvae (Nagrare *et al.*, 2011). The caterpillars are covered with white mealy material, which is hard to detect amidst mealybugs and serves as an excellent camouflage (Ayyar, 1929; Puttarudriah & Channabasavanna, 1957). Pupation takes place in the mealybug colony and the pupa has a rather characteristic monkey-like or phantom-like appearance, and is known as the monkey-face pupa (Ayyar, 1929).



S.epius larvae feeding on *P.marginatus*



S.epius butterfly

11. Big eyed bug *Geocoris ochropterus* (Fieber)

Big eyed bug *Geocoris ochropterus* (Fieber) (Hemiptera: Lygaeidae) is a polyphagous predatory bug, preys on pest species of field and horticultural crops. In cotton, nymph and adult feed on nymphs of leafhoppers, thrips, red cotton bug and eggs of *H. armigera*, *S. derogata*, *P. affinis* and *P. gossypiella*. It is also associated with pest complex of the maize, sesame, sorghum, potato, okra in various agro climatic zones of India. *G. ochropterus* is reported from India, Pakistan and Myanmar.

Parasitoids

1. *Aenasius bambawalei* Hayat

The newly described species *Aenasius bambawalei* Hayat (Hymenoptera: Encyrtidae) was seen with widespread occurrence of mealybug *P. solenopsis* on cotton and diverse host plants, across three cotton agro ecosystems of India since 2008 onwards. This species played a very significant role in keeping *P. solenopsis* population under control. Parasitism ranged from 5-100 per cent across the country with an average of 30%. The species appears to be host specific to *P. solenopsis*, which has become a serious invasive pest on several hosts like cotton, hibiscus, sunflower, tomato brinjal, etc. The species is now reported from all cotton growing states of India, Sindh and Punjab province of Pakistan (Bodlah *et al.*, 2010, Solangi and Mahmood, 2011), China (Huang *et al.*, 2012).

Hyperparasitoids including *Prochiloneurus pulchellus* Silvestri, *P. albifuniculus* (Hayat et al.), *P. aegyptiacus* (Mercet) (Encyrtidae) and *Promuscidea unfasciiventris* Girault (Aphelinidae) have been recorded on this parasitoid, which reduces its efficacy in the field.



A. bambawalei



Parasitized *P. solenopsis* by *A. bambawalei*

2. *Metaphycus* sp.

Metaphycus sp. (Hymenoptera: Encyrtidae) is a small primary parasitoid of scale insects belonging to families Coccidae, Eriococcidae and Asterolecaniidae (Benzeya and Hayat, 1993). This parasitoid was recorded parasitizing *P. solenopsis* infesting cotton and other hosts in the range 7-10% in central India.

3. *Anagyrus kamali* Moursi

Parasitoid *Anagyrus kamali* Moursi (Hymenoptera: Encyrtidae) is a good candidate for classical biological control of pink hibiscus mealybug. The female wasp punctures a live mealybug body and extracts fluid from the wound. The female wasp feeds on the fluid of the dying mealybug, which provides nutrients to wasp's eggs for development. The female wasp also lays 40-60 eggs inside mealybug, which hatches and the young ones feed internally, killing the mealybug. The parasitoid can complete its life cycle (15-day) in half the time it takes for the entire life cycle of the mealybug (30 days). This parasitoid is also found to parasitize *P. solenopsis* infesting cotton and hibiscus (5-10%) in central India. The species is distributed in India (Delhi, Karnataka, Maharashtra, Tamil Nadu, Uttaranchal, Uttar Pradesh), Egypt, Pakistan, Sri Lanka, China, Indonesia, Java (Hayat, 2006).



Metaphycus sp.



Anagyrus kamali

4. *Anagyrus dactylopii* (Howard),

Anagyrus dactylopii (Howard) (Hymenoptera: Encyrtidae) is found to parasitize *P. solenopsis* and *M. hirsutus* infesting cotton to the lesser extent. The species is widely distributed in India (Andaman and Nicobar islands, Andhra Pradesh, Bihar, Delhi, Goa, Himachal Pradesh, Karnataka, Kerala, Maharashtra, Orissa, Punjab, Tamil Nadu, Uttaranchal, Uttar Pradesh), Oman, Iran, Iraq, Hong Kong, Thailand, China, Indonesia, Java, Hawaii) (Hayat, 2006).

5. *Anagyrus mirzai* Agarwal and Alam

Anagyrus mirzai Agarwal and Alam (Hymenoptera: Encyrtidae) was recorded from *P. solenopsis* infesting cotton and other hosts. The species is distributed in India (Andaman and Nicobar islands, Andhra Pradesh, Delhi, Haryana, Himachal Pradesh, Karnataka, Kerala, Maharashtra, Orissa, Punjab, Tamil Nadu, Uttar Pradesh), Jordan, Pakistan) (Hayat, 2006).

6. *Homalotylus albiclavatus* (Agarwal),

Homalotylus albiclavatus (Agarwal) (Hymenoptera: Encyrtidae) is found to parasitize *P. solenopsis* infesting cotton. The species has been recorded from Himachal Pradesh, Jharkhand, Karnataka, Kerala, Rajasthan, Tamil Nadu, Uttar Pradesh, West Bengal (Hayat, 2006).

7. *Chartocerus kerrichi* (Agarwal)

M. hirsutus was found to be parasitized by *Chartocerus kerrichi* (Agarwal) (Hymenoptera: Thysanidae) (synonym: *Matritia kerrichi* (Agarwal)). *C. kerrichi* is distributed in Andhra Pradesh, Himachal Pradesh, Karnataka, Kerala, Tamil Nadu, Uttar Pradesh (Hayat, 2006).

8. *Pachyneuron leucopiscida* Mani.

Pachyneuron leucopiscida Mani (Hymenoptera: Pteromalidae) is found to parasitize *M. hirsutus* in central India. The species is distributed in India (Bihar, Delhi, Kerala, Tamil Nadu, Karnataka), Croatia, Czech Republic, Czechoslovakia, Europe, Germany, Iran, Israel, Kazakhstan, Kirgizia, Moldova, Slovakia, Sweden, Switzerland, Transcaucasus.



Adult *Palearxista laxa*



Semi looper larvae affected with Tachinids

9. *Palexorista laxa* Curran

Tachnid *Palexorista laxa* (Curran) (Diptera: Tachinidae) is an internal larval parasitoid of Lepidopteran insects such as semilooper and *H. armigera*. It is a non-specific parasitoid and parasitizes a number of lepidopteron larvae like *Chilo partellus* (Swinhoe) and *Eldana saccharina* Walker. They occur during month of August to October. A high host mortality (48%-100%) due to parasite attack occurred when small larvae were parasitized (2nd & 3rd instars). A preference for the 4th and 5th host instars was shown by the flies. *E. laxa* females did not discriminate between previously parasitized and non-parasitized hosts (Van Heerden, 1992).

10. *Rogas aligarhensis* Quadri

Rogas parasitoid, *Rogas aligarhensis* Quadri (Hymenoptera: Braconidae) (synonym: *Aleiodes aligarhensis*) is a larval parasite of the spotted bollworm, *Earias vittella* (Fabricius) on cotton. Parasitism rates of greater than 25% in eggs and 37% in pupae were recorded in Punjab (Sekhon and Verma, 1983). The parasitoid is distributed in India, Bangladesh and Spain.

11. *Campoletis chloridae* Uchida

Campoletis parasitoid *Campoletis chloridae* Uchida (Hymenoptera: Ichneumonidae) is larval parasitoid of *H. armigera* and *S. litura*. It is a key parasitoid of the early instar larvae of *H. armigera* throughout India. The species is widely distributed in India, China and Japan. The female parasitoid deposits its eggs singly in first or second instar host larva, which usually dies in the third or fourth instar. The fully grown parasitoid larva leaves the host to spin a cocoon and pupate on the plant. The parasitization rate ranged from 25.1 to 63.1% (You, 2002).



Rogas



Campoletis chloridae

12. *Apanteles anguleti* Muesebeck

Apanteles parasitoid, *Apanteles anguleti* Muesebeck (Hymenoptera : Braconidae) is a solitary endoparasite of *P.gossypiella* in India and Pakistan. The females prefer 4 to 8 days old larvae for oviposition and the maximum eggs are deposited in 6 day old larvae.



Apanteles anguleti



Parasitized larvae of semilooper

13. *Acerophagus papayae* Noyes & Schauff

A solitary endoparasitoid *Acerophagus papayae* Noyes & Schauff (Hymenoptera: Encyrtidae) is native to Mexico, was introduced in many countries viz., USA, Sri Lanka, Maldives for biological control of papaya mealybug *P. marginatus*. Similar introduction of this parasitoid, apparently with the host, has been reported from Bogor, Indonesia. It parasitizes the early stage (II instar) nymphs of the mealybug. NBAll imported three species of exotic parasitoids namely *Acerophagus papayae*, *Anagyrus loeckii* and *Pseudoleptomastix mexicana* specific to control *P. marginatus* from Puerto Rico in 2010 with the help of USDA-APHIS. These parasitoids have been mass produced and released in mealybug affected areas of Tamil Nadu, Kerala, Karnataka, Andhra Pradesh, Maharashtra and Tripura (ICAR, 2011). Subsequently, natural occurrence of *A. papayae* was also observed in mealybug infested papaya fields at Pune, Maharashtra. The study undertaken for the DNA barcoding of *A. papayae*, using CO I region revealed that the *A. papayae* populations from Pune and USA were identical (Venkatesan *et al.*, 2011). Establishment of *A. papayae* on *P. marginatus* on cotton has been confirmed by Dharajothi *et al.* (2011) in south India. A recent finding supported that *A. papayae* had parasitism up to 31.0% and was more efficient in controlling *P. marginatus* in Minnosata, USA (Amarasekare, 2009). The parasitoid has also been recorded parasitizing *P. marginatus* from Nagpur district.



Acerophagus papayae



Aprostocetus sp.

14. *Aprostocetus* sp.

Aprostocetus sp. (Hymenoptera: Eulophidae) was found to parasitize *P. solenopsis* about 8.5 and 60% at Akola and Jalna respectively, during 2012.

15. *Aprostocetus bangaloricus* Narendran,

Aprostocetus bangaloricus Narendran, (Hymenoptera: Eulophidae.) is a solitary parasitoid found to parasitize *P. solenopsis* and *M. hirsutus* in central India. The species is distributed in India, Brazil, Canary Islands, Italy, Pakistan, Panama, Poland, and USA.

16. *Encyrtus aurantii* (Geoffroy)

Encyrtus aurantii (Geoffroy) (Hymenoptera: Encyrtidae) has been found to parasitize *P. solenopsis* and *M. hirsutus* in central India. Historically this species has been recorded as a primary parasitoid of many species of soft scales including *Coccus* spp., *Pulvinaria* spp., *Saissetia* spp., and *Chloropulvinaria* sp. (Hayat and Subba Rao, 1986; Graham, 1969; Sugonjaev and Gordh, 1981); *Chloppulvinaria psidii* (Bhuiya et al., 1997) *Saissetia coffeae*, *S. oleae*, *S. nigra*, *Coccus viridis*, *C. hesperidum*, *C. pseudomagnoliorum*, *Planococcus citri*, *Pseudococcus longispinus* (Noyes, 2013). It is distributed in India, Australia (Malipatil et al., 2000); some countries in Afrotropical, Australasian, Nearctic, Neotropical, Oriental and Palaearctic regions (Noyes, 2013).

17. *Bracon greeni* Ashm.

Bracon parasitoid, *Bracon greeni* Ashm. (Hymenoptera: Braconidae) is a larval parasitoid of pink bollworm and boll weevil. It is an ectoparasite of the larvae *Eublemma amabilis* a predatory larvae of lac insect *Laccifer lacca* Kerr.

18. *Bracon lefroyi* Dudgeon & Gough

Endoparasitoid *Bracon lefroyi* Dudgeon & Gough (Braconidae: Hymenoptera) effectively check the field population of Pink bollworm (*Pectinophora gossypiella* Saunders) with parasitism ranging from 25-81%. Parasitism was noticed on dissection of green bolls collected from various genotypes of non Bt cotton at CICR, Nagpur during last week of November to first week of December, 2013. During November parasitism was 81% while in December it was 25.71 %. Early season



Adult *B. lefroyi*



Dead pink bollworm larvae with parasitoid larva

pink bollworm populations suffered more larval mortality as compared to later season pink bollworm populations due to this parasitoid.

19. *Microchelonus versatilis* (Wilkinson)

Braconid parasitoid *Microchelonus versatilis* (Wilkinson) (Hymenoptera: Braconidae) is egg-larval parasitoid of *H. armigera*.

20. *Aphelinus* sp.

Nymphs and adults of parasitic wasp *Aphelinus* sp. (Hymenoptera: Aphelinidae) are parasitic on cotton aphids. Aphelinids are parasitoids of soft bodied homopterans. *Aphelinus* sp are endoparasitoids of cotton aphids. They measure about 0.6-1.0mm in length, body is non metallic in appearance. Adult aphelinids feed on honeydew excreted by their hosts.

21. *Trichogramma chilonis* Ishida

Trichogramma chilonis Ishida (Hymenoptera: Trichogrammatidae) are small parasitoids that attack and kill the eggs of a variety of lepidopterous pests. In cotton, they particularly parasitize bollworm eggs, thus killing bollworms before they can inflict damage on the host plant. The use of *Trichogramma* reduces chemical spraying and preserves predators or natural enemies. *T. chilonis* are host-specific, thus safe to use, establish well in tropical agro-ecosystem, can be integrated with other control measures, cheap and can be mass-reared conveniently in the laboratory on *Corcyra* eggs. In the Bt-cotton era, *T. chilonis* lost its relevance as maximum neonates get killed with Bt toxin and application of *Trichogramma* becomes redundant. However, in non Bt or organic cotton, *T. chilonis* can play significant role in bollworm management.

Hyperparasitoids

1. *Promuscidea unifasciiventris* Girault

Promuscidea unifasciiventris Girault (Hymenoptera: Aphelinidae) was observed to be hyperparasitic on *A. bambawalei*. This may impact on populations of the *A. bambawalei*. Besides *A. bambawalei* it is parasitic on several species of mealybugs and also hyperparasitic on other parasitoids such as *Anagyrus* spp., *Aenasius advena*, *Microterys* sp., *Comperiella bifasciata*, and *Cephaleta brunniventris*. The species is distributed throughout India (Andhra Pradesh, Assam, Bihar, Delhi, Jammu & Kashmir, Karnataka, Kerala, Madhya Pradesh, Maharashtra, Orissa, Punjab, Tamil Nadu, Uttar Pradesh, West Bengal, Andaman & Nicobar Islands), Pakistan and China (Hayat, 1998).

2. *Prochiloneurus albifuniculus* (Hayat et al.)

Prochiloneurus albifuniculus (Hayat et al.) (Hymenoptera: Encyrtidae) is a common hyperparasitoid of primary parasitoids of mealybugs such as *P. solenopsis*, *Nipaecoccus* spp., *Coccidohystrix insolita* (Green), etc. Hayat (2006) has provided a list of host insects / plants associated with *P. albifuniculus*. The species is distributed in India (Assam, Andhra Pradesh, Bihar, Goa, Haryana, Himachal Pradesh, Rajasthan, Karnataka, Kerala, Maharashtra, Punjab, Tamil Nadu, Uttar

Pradesh) and South Africa (Hayat, 2006).

3. *Prochiloneurus pulchellus* Silvestri

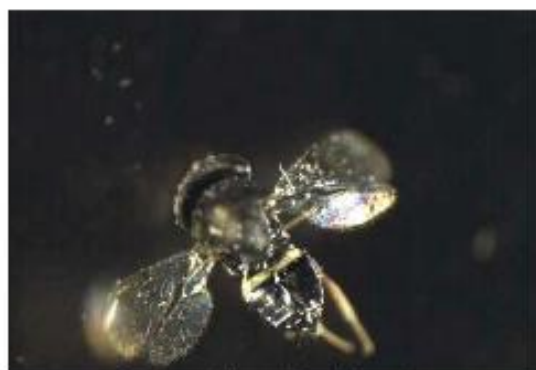
Prochiloneurus pulchellus Silvestri (Hymenoptera: Encyrtidae) is hyperparasitoid of primary parasitoids of mealybugs such as *P.solenopsis*, *Nipaecoccus* spp, *Coccidohystrix insolita* (Green), etc. The species is distributed across India (Andhra Pradesh, Bihar, Goa, Haryana, Karnataka, Kerala, Maharashtra, Punjab, Tamil Nadu, Uttar Pradesh), South Africa. A summarized list of host insects associated with *P. pulchellus* has been provided by Hayat (2006).

4. *Prochiloneurus aegyptiacus* (Mercet)

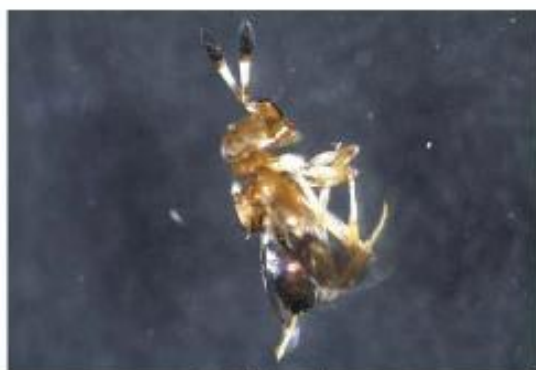
Prochiloneurus aegyptiacus (Mercet) (Hymenoptera: Encyrtidae) is a hyperparasitoid of primary parasitoids of mealybugs like *M.hirsutus*, *N. viridis*, *P. solenopsis*, etc. It is distributed in India (Kerala, Karnataka, Tamil Nadu), West Palaeartic, Egypt and Africa (Hayat, 2006).

5. *Homalotylus eytelweinii* Ratzeburg

Homalotylus eytelweinii Ratzeburg (Hymenoptera : Encyrtidae) was found to parasitize coccinellid predator *Cheilomenes sexmaculata*. About 89.2% parasitism by *H.eytelweinii* was recorded at CICR during July-Sept 2008. They parasitized *C. sexmaculata* in larval stage and not adult. More than one larva has been found to emerge from the parasitized grub. Parasitized, dead, blackened grubs are restricted to the upper leaves. Adult *H. eytelweinii* is black in colour.



Promuscida unifasciiventris



P. albifuniculus



Prochiloneurus pulchellus



Homalotylus eytelweinii

Pathogens of cotton insect pests

1. *Nomuraea rileyi* (Farlow) Samson

Nomuraea rileyi (Farlow) Samson (Moniliales : Deuteromycetes) is an important mortality factor of many lepidopteran insects throughout the world (Lingappa and Patil, 2002) and is being developed as a microbial insect control agent for various noctuid pests infesting a variety of crops. *N.rileyi* is one of the most common and important natural mortality factors on cotton pests *H.armigera*, *S.litura* and semiloopers and has greater significance in the bio-intensive IPM under selective ecological niche. The fungus is capable of causing spectacular epizootics in lepidopteran larvae of cabbage, clover, soybean (Ignoffo, 1981, Thorvilson *et al.*, 1985), groundnut, castor, potato, cotton, etc. (Lingappa and Patil, 2002, Patil *et al.*, 2003, Manjula *et al.*, 2003 and 2004). Soil acts as the natural reservoir of conidia that starts the annual epizootic (Ignoffo *et al.*, 1977).

2. Nuclear polyhedrosis virus

The nuclear polyhedrosis virus (NPV) (Baculoviruses) is pathogenic to predominantly caterpillar group of insects especially *H.armigera*. The virus infected insects exhibited symptoms of discolouration of body, regurgitation, decomposition and lethargy. The virus transmitted from insect to insect through crystals in all of their bodily emissions. As the virus is in the crystal-like capsid, it requires to be broken down by the alkaline digestive system of the insects to be released. Mortality in infected insects was found to be nearly 100% for the control of *H.armigera* infesting cotton, gram and pigeon pea. HNPV is recommended at 250LE/ha against *H.armigera* in cotton. In organic cotton production HNPV can be useful as IPM component.

3. Entomopathogenic nematodes

Entomopathogenic nematodes (EPN) in recent years have been recognized as potential bioagents against wide array of insect pests. The relatively rapid death of the insect host (24-48h), wide host range, non-toxicity to mammals, amenability to mass production protocols and host-finding ability of these nematodes has generated great interest in their use as component of IPM protocols.

There are two genera of Entomopathogenic nematodes viz. *Heterorhabditis* and *Steinernema* spp. The nematodes belonging to *Steinernema* penetrate insects through natural body openings as mouth, anus and spiracles while nematodes belonging to *Heterorhabditis* can also directly puncture cuticle due to presence of tooth in mouth region. Insects infected with EPN are typically characterized by flaccid appearance with characteristic change of colour to yellow, brown or orange in *Steinernema* infection while *Heterorhabditis* infected insects appear brownish red to brick red that faintly luminescence in the dark.

EPN are symbiotically associated with a bacterium species (*Photobacterium* spp. and *Xenorhabdus* spp.) which live within nematode's gut. Once inside the body cavity of insects, these bacteria are released. These bacteria multiply quickly. Insect kill is achieved due to toxin produced by both nematode and the bacterium. When host contents have been consumed, the infective juveniles armed

with bacteria emerge from empty shell of insect and move into the soil to search for new host.

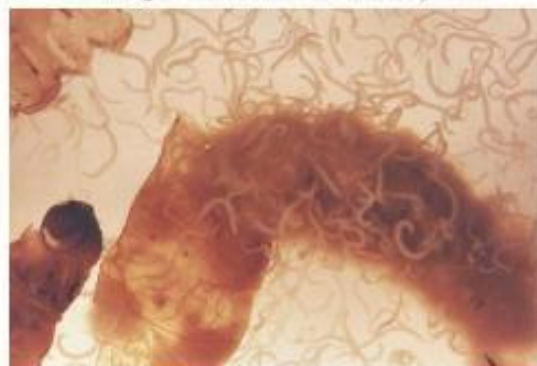
EPN belonging to *Heterorhabditis indica*, *H.bacteriophora*, *Steinernema glaseri* and *S.siamkayai* isolated from cotton ecosystem were found very potential against larvae of cotton bollworms. All the stages of *H.armigera* were found to be susceptible and insect mortality ranged between 88-98% at inoculums level of 15 infective juveniles per larva in 24- 48h. Other insect pests as semilooper, leaf roller, pink bollworm and spotted bollworm were also found to be susceptible to EPN. EPN isolates native to cotton ecosystems were found better adapted as *H. armigera* antagonist. (Gokte-Narkhedkar *et al.*, 2001, Gulsar Banu *et al.*, 2007). Mass multiplication protocols for providing inoculums for field application have been standardized. EPN can be mass reared on field collected or lab reared insect larvae (*Helicoverpa*, *Corcyra*, *Galleria*, *Anomis* etc.), nutrient broth based Wouts's medium and animal kidneys (Gokte-Narkhedkar *et al.*, 2005, 2008, 2009).



H. armigera infected with *H.bacteriophora*



Developing EPN seen beneath the insect cuticle



Infective EPN juveniles emerging from female



Culturing EPN on *Galleria melonella*

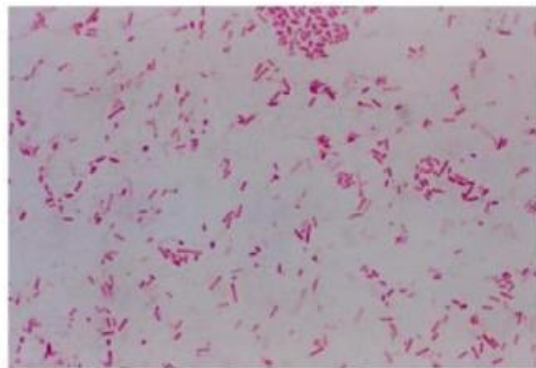
4. Bacterial symbionts as source of new insecticidal toxin genes

It is well known that EPN owe their toxicity largely to bacterial symbiont associated. Pathogenicity of bacterial symbionts of two entomopathogenic nematodes viz., *Xenorhabdus* sp and *Photorhabdus* sp. alone and their cell free extract at different doses showed that the mortality of the *H. armigera* third instar larvae significantly increased with the time. Cent per cent mortality was achieved when the larvae were treated with *Xenorhabdus* sp., *Photorhabdus* sp, @ 200 μ L at 6 DAI. Bacterial symbiont *Photorhabdus luminescens* from EPN, *H. indica* was also found as viable

management option against sucking pests of cotton (Gokte-Narkhedkar *et al.*, 2006). Thus these bacterial symbionts associated with native EPN isolates can be potential source of insecticidal toxin genes.



Primary phase *P.luminescens*



Stained bacteria *P.luminescens*

Pest management strategies

1. Pre season and in-season cultural, mechanical and physical methods for minimizing pest population

S. No.	Physical/ cultural/ mechanical practices	Target pest(s)	Impact
	Bt cotton/ non Bt cotton		
1.	Use of sucking pest tolerant genotypes tested and recommended for the agro ecological zone	Sucking pests	Reduce pesticidal sprays
2.	Use good quality seed from reputed dealer /firm	Sucking pests and / or bollworms	Spurious seed may be susceptible to sucking pests and / or bollworms
3.	Growing of non Bt (20% refuge) or pigeon pea around Bt-cotton field	ABW, SBW, PBW	Delay of resistance to Bt
4.	Destruction of cotton stalk and weeds during off-season and in-season	Mealybug, Whitefly, CLCuD	Reduces carry over of pest infestation
5.	Growing strips of pigeon pea/ bajra/ sorghum/ maize crop	Mealybug	Act as a physical barrier and check spread
6.	Installation of yellow sticky trap	Whitefly	Monitoring and managing whitefly population
7.	Avoid cultivation of okra	Leafhoppers, Whitefly, SBW, ABW	Most preferred host, help to increase population build up and incidence on cotton crop

S. No.	Physical/ cultural/ mechanical practices	Target pest(s)	Impact
8.	Avoid spraying of insecticides	Semilooper, leaf folder	They do cause negligible damage to crop, act as a repository of natural enemies
9.	Avoid disposal of uprooted infested plant/ weeds in water channel/ common place	Mealybug	Check further spread
10.	Restrict movement of farm animals/ implements/ workers/cotton stalks from infested field during season	Mealybug	Reduces spread of mealybug infestation
11.	Avoid ratoon crop	Mealybug, PBW	Reduces carry over
12.	Crop rotation with non host crop plants, use of high seed rate, thinning of the affected plants, removal and destruction of affected plants, growing cotton in the ridge and furrow system, earthing up 15-20 days after germination.	Stem weevil	Reduce carryover of pest population in south India
13.	Avoid spraying of pyrethroids and mixture containing them on cotton or other host crops that may harbor ABW during the period (e.g. soybean)	ABW	Delayed resistance to insecticides and prevent outbreak of ABW
Non Bt cotton			
1.	Timely termination of crop	ABW, SBW, PBW	Reduces carry over
2.	Pre season deep ploughing	ABW, TC	Pupal mortality through bird feeding and high temperature
3.	Removal of infested terminal shoots	SBW	Reduces incidence
4.	Collection and destruction of egg masses and early instar feeding gregariously along with leaves	TC	Reduces population build up and incidence

S. No.	Physical/ cultural/ mechanical practices	Target pest(s)	Impact
5.	Collection and destruction of bad opened bolls, grazing of cattle, sheep, goat after last picking	PBW	Reduces carry over

2. Pest surveillance

- Field survey/ scouting for pests should be undertaken at 3 – 5 days interval to workout ETL.
- For sucking pests, damage should be assessed on the basis of infestation grades.
- For bollworms (American & Spotted) infestation should be worked out by observing percent flared up squares in case of non-Bt.
- For pink bollworm per cent damage should be worked out by destructive sampling of green bolls of non Bt.
- Use pheromone traps for monitoring of American bollworm, spotted bollworms, pink bollworm in non-Bt cotton.
- Use yellow sticky trap for monitoring whiteflies and leafhopper.
- Install pheromone traps at a distance of 50 m @ five traps/ ha for each insect pest.
- Use specific lures for each insect pest species and change it after every 15 – 20 days.
- Trapped moths should be removed periodically.



Pheromone trap



Yellow sticky trap

3. Economic Threshold Levels (ETLs)

Based upon the result of survey/field scouting etc for different pests, farmers are advised to initiate pest management practices accordingly as soon as the pest crosses ETL. The ETLs for major pests are as under.

Insect	ETL : Pest count in a sample of 20 plants per acre
Leafhoppers	≥5 plants showing (25% plants infested) damage grade II/ III/ IV
Thrips	≥5 plants showing silvery patches on underside of leaves above mid canopy (25% plants infested)
Whitefly	≥10 plants having ≥10 whiteflies/plant (50% plants infested)
Aphids	≥2 affected plants counted randomly showing symptoms cupping / crumpling of few leaves on the upper portion of plant (10% plants infested)
Mealybugs	≥20 plants/acre showing damage grade II/ III/ IV
Mirid bugs	≥5 mirid nymphs or adults per plant (from top canopy squares) (25% plants infested)
Spodoptera	≥2 Egg mass / cluster of gregarious larvae
Spodoptera	≥10 infested plants (50%) having ≥5 solitary full grown larvae/plant
	Bollworms (in case of Non Bt)
Bollworms American & Spotted)	20% plants having one or more flared up square
Pink bollworm	More than 8 moths / trap per night for 3 consecutive nights or more than 10 % infested flowers or bolls with live larvae.

4. Pictorial representative of sucking pest grades

Leafhoppers



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

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 : Presence with no 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

MEALYBUG



Grade I

Grade II

Grade 0 : Plant without mealybug infestation

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

5. Advisory for probable situations of insect pest incidence

Pest	Do	When
Crop growth stage: 0-60 DAS		
Spodoptera	<ul style="list-style-type: none"> • Collect and destroy egg masses/ gregarious larvae/ solitary larvae by hand picking. • Remove and destroy egg masses and larvae. • Spray crop with Neem oil 5ml/l +5% NSKE+ 1gm detergent powder per litre water to kill residual larvae • Spray Clorantraniliprole 18.5 SC 50 g a.i./ha 	<p>Under emergency situation for the control of early season Spodoptera, American & Spotted bollworm)</p>
Mealybugs	<ul style="list-style-type: none"> • Destroy congress grass and other weeds from field and field boundaries prior to the onset of seasons • Avoid spraying of any chemical insecticides during initial crop growth stage. • Do not disturb young cotton plants that have slight infestation of the mealybugs in early stages of the crop because mealybug crawlers spread through human interventions. • Initial infestation would be suppressed by native natural enemies in due course of time. 	
Sucking pests	<ul style="list-style-type: none"> • Avoid spraying of any chemical insecticides during initial crop growth stage as Bt-cotton seeds with host plant resistance to sucking pests are seed treated with insecticides. • During the initial phase of crop growth, natural enemies are abundant and keep the pest population under check. • Sprays of harmful chemicals destroy the natural enemies. 	

	<ul style="list-style-type: none"> • Avoid repeated sprays of neonicotinic group of insecticides against sucking pests. • Spray Flonicamid 50 WG 200 g/h (need based) 	25 % plants infested by sucking pest
Crop Growth Stage: 60-90 DAS		
Bollworms	<ul style="list-style-type: none"> • Spray Cloranthraniliprole 18.5 SC 50 g a.i./ha (need based) 	20% plants having one or more 'flared up squares' by bollworms in case of Non-Bt
Mealybug	<ul style="list-style-type: none"> • Destroy congress grass • Remove infested plants in plastic bag and destroy. • Conserve parasitoid, <i>Aenasius bambawalei</i> and <i>Acerophagus papayae</i> by avoiding harmful chemicals. • Apply Acephate 75% SP 10gm/l of water on stem or near root zone. 	20 plants/ acre exceed Grade-II/III/IV by mealybug
Leafhoppers & whiteflies	<ul style="list-style-type: none"> • Spray Flonicamid 50 WG 200g/ha (if not sprayed during 0-60 DAS) or Buprofezin 25 % SC 100g/ha or Acephate 75 % SP 292g a.i./ha 	25% plants shows Grade II/III/IV by leafhoppers. 50% plants infested by whiteflies.
Leaf reddening	<ul style="list-style-type: none"> • Irrigate the field • Apply spray of MgSO₄ 1 %, Urea 2%, followed by DAP 2%. 	At the time of initiation of leaf Reddening
Crop Growth Stage: 90-120 DAS		
Bollworms	<ul style="list-style-type: none"> • Spray Flubendiamide 480 SC 125ml/ha or Indoxacarb 14.5 SC 75 g a.i./ha or Spinosad 45% SC 75 g a.i./ha (need based) 	20% plants having one or more 'flared up square' by bollworms in case of Non-Bt
Leaf hopper, Whiteflies, Thrips	<ul style="list-style-type: none"> • Spray Thiamethoxam 25%WG 25 g a.i./ha • Spray Polo Diafenthion 50SC 300g a.i./ha against whiteflies 	25% plants shows Grade II/III/IV symptoms by leafhoppers. 50% plants affected by whiteflies. 50% plants showing silvery patches on underside of leaves by Thrips.

Pink bollworm	<ul style="list-style-type: none"> • Install pheromone traps at a distance of 50 m @ five traps per ha. • Use gossypure and change it after every 15–20 days. 	Crop history shows infestation by pink bollworm in previous years
Pink bollworm	<ul style="list-style-type: none"> • Spray Fenvalerate 20% EC 75-100g a.i./ha 	8 moths/trap/night over 3 consecutive nights
Crop Growth Stage: >120 DAS		
Pink bollworm & Mealybug	<ul style="list-style-type: none"> • Spray Thiodicarb 75 WP 1500g a.i./ha or Quinalphos 25 % EC 500g a.i./ha or Chlorpyrifos 20 % EC 250g a.i./ha 	10% infested flowers/ bolls with live larvae of Pink bollworm in case of Non Bt 20 plants/ acre having infestation Grade II/III/IV of Mealybugs

Management of sporadic pests limited to south India

T Mosquito bug, *Heliopeltis bradyi* Waterhouse.

- Regular scouting for incidence of pest
- Check the incidence on neem and moringa trees around cotton.
- Any neem based insecticide (3-5 ml/l) or neem seed kernel extract (5%) as prophylactic measure during peak boll formation stage.
- Application of Profenofos 50% EC @ 2 ml/l or Acephate 75%SP @ 1 g/l

Stem Weevil, *Pempherulus affinis* Faust

- Reduce cropping intensity and high seed rate.
- Destroy affected and dried plants and earthing up to prevent oviposition.
- Apply of Neem cake (150 kg/ha)+Carbofuran (1kg a.i./ha) at 15-20 DAS
- Stem drenching with Neem seed extract 5% from 45 DAS, 4 times at weekly interval or drenching with Chlorpyrifos 0.1%, 4 times at weekly interval from 45 DAS.

Flower bud maggot *Dasineura gossypii* Fletcher

- Apply Malathion 50 EC @ 2 ml/l during square formation.

6. Do's and don'ts in IPM/IRM

i. Avoid neonicotinoid and organophosphate sprays for sucking pest control in early season pest. Why?

CICR recommends the use of varieties/ hybrids with host plant resistance to sucking pests. The recommended Bt cotton hybrid seeds available in the market

are treated with Gaucho® (Imidacloprid 70WS) or its equivalent. At the time of introduction, Gaucho® seed treatment was found to confer protection against leafhoppers and other sucking pests up to 40-45DAS. Therefore, it is important to avoid neonicotinoid such as Confidor (Imidacloprid 17.8 % SL) and related insecticides as foliar sprays so as to prevent further additional selection pressure. This window support native natural enemies activity. Broad spectrum organophosphates such as Monocrotophos, Methyl demeton, Phosphamidon, etc. strongly disrupt the natural enemy populations.

On May 24, 2013, the European Commission imposed restrictions on use of neonicotinoid insecticides especially (clothianidin, imidacloprid and thiametoxam) for a period of two years due to their affect on honey bees.

ii. Do not spray against minor lepidopteran insects. Why?

Minor lepidopteran insects such as the cotton leaf folder, *Sylepta derogata* and cotton semilooper, *Anomis flava* cause negligible economic damage to cotton but serve as hosts for parasitoids such as *Trichogramma* spp., *Apanteles* spp and *Sysiropa formosa*, that attack *H. armigera*.

iii. Foliar spray of MgSO₄, 2% Urea followed by 2% DAP. Why?

Application of foliar spray of MgSO₄, 2% Urea followed by 2% DAP to ensure proper cry toxin expression and also to reduce problem of leaf reddening. Spray of 1% cobalt chloride and soil drenching with Bavistin 1 % in the initial stage of wilt was found to help in the recovery of plants.

iv. Use Coragen/Fame/ Emamectin benzoate/Indoxacarb/Spinosad on non-Bt-cotton at ETLs of 20% infested plants. Why?

These are highly effective on *H. armigera*. Apart from its toxicity to *H. armigera*, Spinosad is also effective on *E. vittella*. They have a high selective toxicity towards the target pests while being less toxic to many beneficial insects in the cotton ecosystem. They belong to the class II and below categories of insecticides. Spinosad should not be used in mealybug infested field as it causes resurgence of mealybugs.

v. Use organophosphates or carbamates only once as effective larvicides for bollworm control at ETLs of 20 % plants showing flared up squares. Why?

Insecticides such as Acephate, Thiodicarb and Quinalphos are also help in keeping mealybug, mirids, thrips, tobacco caterpillar and pink bollworm populations under check during late season. Resistance levels against certain organophosphate group of insecticides (Acephate, Quinalphos, Chlorpyrifos & Profenophos) and carbamates (Thiodicarb and methomyl) have been found to be low in most populations tested. These insecticides are very effective for bollworm control but have low ecological selectivity and can be harmful to

beneficial insects. The populations of beneficial insects in cotton ecosystem are generally low in later part of this window and hence the application of organophosphates and carbamates is rational.

vi. Pyrethroids are ideal for pink bollworm management. Why?

The application of pyrethroids as late season sprays would be ideal for pink bollworm management. Pyrethroid resistance in *H. armigera* is generally high, but pyrethroids are very effective against pink and spotted bollworms and are suited for the late season. Spray can be augmented when 8 pink bollworm moths/trap/ night observed for 3 consecutive nights or >10 % infested bolls. Pyrethroid deter pink bollworm moth from alighting on treated surface, thus preventing egg laying.

vii. Do not use phosphamidon, methyl parathion, phorate, monocrotophos, dichlorovos, carbofuran, methomyl, triazophos and metasystox for mealybug control. Why ?

These insecticides are not only ecologically hazardous, but are also detrimental to several important predatory insects such as the coccinellid beetles and several parasitoid wasps that control mealybugs and other insect pests. Insecticide use should be minimal so as to conserve naturally occurring control by beetle species and wasps which devour mealybugs. Insecticide sprays cause the dispersion of crawlers to neighbouring plants, thus facilitating their spread and exacerbating the problem.

8. Details of insecticides suggested against cotton pests

Insecticides	WHO rating (2009)	Activity	Target pests	Recommended dose	Commercial names
Biorationals					
Neem based insecticides		Antifeedent	TC, sucking pests	2.5 l/ha	Azadirachtin based formulations: Bioneem, Econeem, Achook, Margocide, Multineem, Neemactin, Neemark, Neemazal, Neembicin, Neem Gold, Neemnath.
NSKE		Antifeedent	TC, sucking pests	25 kg seed/ha	
HNPV		Stomach	ABW	500 LE/ha (3x10 ¹³ PIBs)	Elcar, Helicide, Prakruthi Rakshak 100. PIBs = Poly inclusion bodies.
Neonicotinoid					
Imidacloprid 17.8 % SL, 30.5% SC	Class II	Binds irreversibly to post synaptic nicotinic acetyl-choline receptor	Leafhoppers	20 g a.i./ha	Confidor, Merit, Premise, Admire, Provado, Premier, Marathon, Touchstone, Advantage, Midas 2000, Mex, Sanfidor
Thiomethoxam 25 % WG		Stomach, contact and systemic activity	Leafhoppers	25 g a.i./ha	Aclara, Cruiser, Platinum, Flagship, Meridian, Exaam, Centric, Cruiser, Willoxam, Anant, Evident
Carbamates					
Thiodicarb 75 % WP	Class II	Stomach & contact	Boltworm	1500 g a.i./ha	Thiodicarb, Larvin, Larvin brand, Securex, Semevin.
Carbofuron 3G	Ib	Systemic	Borers Nematodes	1kg a.i./ha	Furadan, Curaterr, Yaltox, Bay 78537, D 1221 ENT 27164, FMC 10242, NIA 10242
Anthranilic diamides					
Chlorantraniliprole 20%EC	U	Activate insect ryanodine receptors	ABW	50g.a/ha	Renaxypyr, Coragen, Aitacor
Pyridinecarboxamide					
Fonicamid 50% WG		Systemic & Translaminar	sucking insects	200gm/ha	Ulala
Benzenedicarboxamides					
Flubendiamide 480SC		Stomach insecticide with a new target site - Ca ⁺ release channels	Lepidopteran pests	100 -125 ml/ha	Fame
Insect Growth Regulators					
Diflubenzuron 25 % WP	Class III	Non-systemic	Lepidopteran pest	75-100 g a.i./ha	Dimilin, Empire, Micromite

Novaluron 10 % EC	U	Non-systemic, IGR	Lepidopteran pests	40-60 g a.i./ha	Rimon, Counter, Pedestal
Lufenuron 5 % EC	U	Non-systemic, IGR	Lepidopteran pests	10-50 g a.i./ha	Match, Lufenuron tech
Diapenthiuron 50 % WP	Class III	ATPase inhibitor	Whiteflies and sucking pests	300 g a.i./ha	Polo, Pegasus, Dicare
Buprofezin 25 % SC	Class III	Chitin Synthesis inhibitor	Whiteflies and sucking pests	100 g a.i./ha	Phylaud, Accolade, Viappla mixtures, Dadecei, Deligent, devifezin, Buplon, Applaud, Jawa

Oxadiazine

Indoxacarb 14.5 % SC	Class II	Block sodium channel in Nerve axon	Lepidopteran pests	75 g a.i./ha	Avaunt, Dhawa, Steward, Torondo, Encounter
-------------------------	----------	--	-----------------------	--------------	---

Macrocyclic lactone (spinosyns)

Spinosad 45 % SC	Class III	Contact and stomach	ABW, SBW & thrips	75 g a.i./ha	Tracer, Naturalyte, Success, Conserve, Audienz, Biospin, Boomerang, Caribstar
---------------------	-----------	------------------------	----------------------	--------------	---

Organophosphate


Acephate 75 % SP	Class II	Broad spectrum systemic, ovicidal, contact and stomach	Leafhoppers, Whitefly, Bollworms	584 g a.i./ha	Acatin, Ace, Aceveer, Acevol, Afasan, Asafat, Daraphate, Gaycep, Growlaf, Mollthene, Orthene, Starthene, Tremor, Tameron Gold, Acefate, Acemil, Spit fire, Agrophate, Aimthene, Asataf, Kayphate, Lancer, Orthene, Ortran, Ortril, Pilarthene, Starthene, Surpass, Tomado, Trophy, Vital, Lucid, Hythene, Missile
Chlorpyrifos 20 % EC	Class II	Non- systemic, contact, stomach, and vapour action	All cotton pests	250 g a.i./ha	Blaze, Chlorosan, Chlovip, Classic- 20, Dursban, Fantom, Gayachlor, Gold 25EC, Growban, K-Ban, Lethal, MIG-20 TC, Pyrivol, Radar, Strike, Suban, Tricel, Trishul, Agrofos, Atlas Sheriff, Banusban, Chlorofos, Classic, Coroban, Crossfire, Danusban, Dursban 2-E, Detmol, Detmolin, Dimlor, Drexar lawn Granules, Dummel, Empire, Fullback, Gilmore, Gilphos, Gladiator, Gustafson Lorsban 30 Flowable, Gustafson Lorsban 50-SL, Hexaban, Hockley Chlorpyrifos, Hyban, Lethal, Lorsban-T, Point Chlorpyrifos, Predator, Prentox Residual Concentrate DV-One, Pychlorex, Pyrenone Dursban Dual Use, Pyriban, Pyrinex, Radar, Ruban, Salut, Saluthion, Schwab

					EX, Spannit Granules, Suban, Sulban 20, Talon, Terminate, Terraguard 48 EC, Terraguard Plus, Twin Span, Starban.
Profenophos 50 % EC	Class II	Non-systemic, stomach and contact	Bollworm	750-1000 g a. i. /ha	Curacron, Kitazin, Fenom C, Polytrin C, Seleccion, Curacron, Prowess, Profenovip, Profex, Carina, Prahar
Quinalphos 25 % EC	Class II	Translaminar stomach and contact	Bollworm	500 g a. i./ha	Agriphos, Agroquin, Agroquina I, Award, Bayrusil, Desalux, Dhanulux, Ekalux, Entolux, Gilquin, Hilquin, H-LX, HLX-35, Hockley Quinalphos, Hyquin, Kemlox, Keterphos, Kilex Quinalphos, Kinalux, Knave, Milux, Pharulux, Quinal, Quinaltaf, Quinatox, Ramlux, Savall, Sicophos, Solux, Starbrand, Suquin, Tagquin, Tombel, Vazra, Starlux
Malathion 50%SC	Class III	Contact, stomach & respiratory action	Sucking pest		Jaithion, Chemethion, Topsen, Sandoz, Lathiock

Synthetic pyrethroids

Fenvalerate 20 % EC	Class II	Non-systemic, stomach and contact	Bollworm	75-100 g a.i./ha	Darafen, Fencin, Fencron, Fenfen, Fenkil, Fenmil, Fenmol, Fenok, Fensaana, Fenvip, Field Marshall, Froten, Milfen, Parryfen, Spicfen, Starfen, Sumicidin, Ag-Fen, Agrofen, Agrophen, Bangfenn, Belmark, Capvalerate, Chatri, Devi fenvalerate, Fapfen, Fencid, Fenoim, Fencron, Fen-Fen, Fenhit, Fencidin, Fenis, Fenkem, Fenkill, Fenkil, Fenoron, Fenrio, Fenval, Fighter, Gayafen, Gilmore Fenvalerate, Gilten, Grofen, Hilfen, Hitten, Hockley fenvalerate, Hyfen, Kagrofen, Kayvalerate, Lufen, Milfen, Monocil, Motofen, Parafen, Paratem, Parryfen, Pavshafen, Pensil, Pyridrin, Ramfen, Sicofen, Starfen, Sujafen, Sumicidin, Sumifly, Sumitox, Sunvale EC, Tagfen, Tirade, Trifen, Triumphcard, Valour, Vegfro, Vifen, Vikafen
------------------------	----------	---	----------	---------------------	---

9. Classification of the insecticides based on toxicity

Classification of the insecticides	Class	Medium lethal dose LD ₅₀ mg/kg body weight of test animal		Label colour	Label
		Oral route	Dermal route		
Extremely toxic	Ia	1–50	1–200	Bright red	
Highly toxic	Ib	51–500	201–2,000	Bright yellow	
Moderately toxic	II	501–5,000	2,001–20,000	Bright blue	
Slightly toxic	III	More than 5,000	More than 20,000	Bright green	

(Source: http://en.wikipedia.org/wiki/Toxicity_label and www.cibrc.nic.in/ppcancase.doc)

10. Calculation of insecticide doses

For high volume spray- knapsack sprayer

Calculation of dose of insecticide in ml or gm /l of water based on a.i /ha
 e.g.- 20 g a.i./ha of Imidacloprid 17.8 % SL

17.8 g a.i - 100 ml of material 17.8 % SL
 20 g a.i. - ? ml of material

$$\frac{20 \times 100}{17.8} = 112.35 \text{ ml}$$

112.35 ml material of imidacloprid 17.8% SL per ha

1 ha – 500 lit water - 112.35 ml of imidacloprid 17.8 % SL
 1 lit water - ?ml of imidacloprid 17.8 % SL

$$\frac{1 \times 112.35}{500} = \text{App.}0.225 \text{ ml/ l water}$$

Note : For power spray tripple volume/quantity of insecticides should be used.



During the last six decades cotton disease scenario has changed significantly. *Fusarium* wilt, root rot, seedling blight, anthracnose and grey mildew were the foremost problems when majority indigenous diploid cottons were being grown. With the maximum area being occupied by upland cotton, bacterial blight became the major problem to which indigenous cottons were highly resistant. *Fusarium* wilt has become less important as upland cotton is immune to Indian race of the pathogen. *Verticillium* wilt which appeared in Tamil Nadu remained restricted mainly to south zone. Grey mildew, once a serious problem for diploid cottons especially in central India has adapted to tetraploid cotton and their hybrids as well. Presently, it is a major problem in central and south India in Bt-cotton hybrids. *Alternaria* blight and *Myrothecium* leaf spots are prevalent all over India but are severe in the states of Karnataka and Madhya Pradesh, respectively. Rust once considered a minor disease in Karnataka and Andhra Pradesh can cause significant losses during seedling stage. In north India, the leaf curl disease caused by a Gemini virus and transmitted by whitefly, *Bemisia tabaci* has become a major threat to cotton cultivation since 1993. Important diseases of cotton are described below categorized into fungal, bacterial and viral diseases.

Fungal diseases

1. Root rot

Root rot is caused by fungus *Rhizoctonia solani*, *R. bataticola* or *Sclerotium rolfsii*.

Symptoms include drooping of leaves and wilting. The infected plants can be easily uprooted, lack secondary roots and discoloration of roots seen.

R. solani and *R. bataticola* infection can be differentiated based on the discoloration and wetness of the infected roots- brown and wet in case of *R. solani*, while black and dry in case of *R. bataticola*. Shredding of bark is another characteristic symptom. The disease first appears in June and becomes vigorous during July. In August, the attack slows down and almost ceases by the end of September. The disease is serious in northern India but also reported from Maharashtra, Bihar, Gujarat, Andhra Pradesh and Tamil Nadu (Srinivasan, 1994). The disease affects both upland and desi cotton species, being more serious on desi cottons (Monga and Raj, 1994a).

Root rot caused by *Sclerotium rolfsii*, a fungus characterized by the production of spherical sclerotial bodies in culture as well as on infected plants. High soil moisture coupled with high temperature favors the infection. Typical symptoms include drying of seedlings associated with rotting of the collar region and downwards. The infected plants when uprooted show lack of secondary roots. The infected roots are whitish in color and often white mycelia of the fungus are visible. The disease is distributed in Maharashtra, Madhya Pradesh, Andhra Pradesh and Tamil Nadu.



Root rot infected field



Infected cotton root



Sclerotium sp. infected cotton root



Wet rot of cotton (*R. solani*)

2. Fusarium wilt

Vascular wilt in cotton is caused by a fungus *Fusarium oxysporum* f.sp. *vasinfectum* that can infect crop at any stage. Dry soil conditions normally favor infection and

often this is associated with nematode infestation, the later facilitating entry of the wilt pathogen. Typical symptoms include loss of turgidity, yellowing and browning of the foliage followed by death of plants. In many cases one branch or a part of the plant exhibits the symptoms due to blocking of xylem vessels in that particular region. Regeneration of plants partially also has been noted in some cases. If the root system is split open, characteristic browning of the vascular bundle is seen. Wilt disease can appear at any stage of plant development. The disease is widely distributed in Maharashtra, Gujarat, Madhya Pradesh, Punjab, Haryana, Andhra Pradesh and Karnataka.



Field view of *Fusarium* wilt



Plant infected with *Fusarium* wilt



Field infected with *Fusarium* wilt



Typical symptom of *Fusarium* wilt- browning of xylem

3. *Verticillium* wilt

Verticillium dahliae penetrates the roots and grows in the water conducting tissue, blocking water uptake and causing wilt symptoms. *Verticillium* affected plant exhibit symptoms of leaf mottling, death of leaf tissue between the veins and around margins, sometimes defoliation, dark brown tan to black coloration of vascular tissue throughout the main stem. The occurrence of disease was found to be mostly in late season or after wet and /or cool weather. Diseased plants can be seen to be scattered throughout the field. Egg plant, sunflower, soybean, potato, tomato and some weeds are the host of pathogen. *Verticillium* wilt has been observed in some areas of Tamil Nadu and Karnataka.

4. Grey Mildew

Grey mildew is caused by the fungus *Ramularia areola* Atk. The disease is

characterized by irregular, angular, pale, translucent spots measuring 1-10 mm in size surrounded by veinlets. The disease appears on the older leaves usually when the plants are reaching maturity. In Maharashtra State, the grey mildew is commonly referred to as 'Dahiya' or 'Dahya' disease because of the symptoms resembling sprinkled curd on foliage (Gokhale and Moghe, 1965). A frosty or mildew growth consisting of conidiophores of the fungus appear first on the under surface and subsequently on the upper surface of affected leaves. As the infection progresses leaves become yellowish brown and fall off prematurely. Majority of released Bt hybrids fall in moderately to highly susceptible category (Hosagoudar *et al*, 2008). The losses extending up to 90 percent has been recorded under exclusive monoculture of 'Diploid' cotton (Sangitrao *et. al.*, 1993) while in intra-hirsutum hybrid H4 (tetraploid cotton), the yield loss to an extent of 62 to 68 per cent has been reported in chemically unprotected crop at disease endemic area of Akola (Shivankar and Wangikar, 1992). The incidence of grey mildew is assuming a serious position in central and southern zone affecting upland, herbaceum and arboreum cotton. The disease is commonly occurring in Maharashtra, Madhya Pradesh, Karnataka, Andhra Pradesh, and Tamil Nadu. There was reduction of loss up to 29.20% as compared to application of five sprays of carbendazim based on experiments conducted at Dharwad, Guntur and Nanded during 2009-11 (Monga *et al.*, 2013).

Historically, the grey mildew disease was reported for the first time on upland cotton in Auburn, Alabama, USA in the year 1890 (Atkinson, 1890), subsequently, the disease was reported by many workers in cotton-growing areas of the world,



Grey mildew on lower surface of leaf



Grey mildew on upper surface of leaf



Severely infected plant in the field



Grey mildew on 'Desi' cotton

affecting all the four commercially cultivated species i.e. *G. hirsutum*, *G. arboreum*, *G. herbaceum*, and *G. barbadense* (Bell, 1981).

5. Alternaria leaf spot

Alternaria leaf spot is caused by a fungal genus *Alternaria*. Three species are reported to cause the leaf spots in cotton- *A. gossypina*, *A. macrospora* and *A. alternata*. Based on pooled results (2007-2009) of experiments conducted at Rahuri, Guntur and Dharwad, it was estimated that *Alternaria* leaf spots cause loss up to 26.6% (Monga *et al.*, 2013). Alternaria pathogen kills the surrounding tissues and produces more spores on the surface of the lesions within a few days. Numerous spores are produced on defoliated leaves on the ground under the crop. Alternaria leaf spots are more severe on lower leaves as compared to upper leaves. Plants with a high boll load are more susceptible than plants with a low boll load. When a susceptible crop is exposed to a favorable environment, defoliation occurs rapidly. The disease is seen in all cotton growing areas, but more serious in Maharashtra, Gujarat, Karnataka, Andhra Pradesh and Tamil Nadu.

A. macrospora causes brown, grey brown or tan lesions 3-10mm in diameter, especially on lower leaves. Sometimes with dark or purple margins and with concentric zones. Affected leaves develop an abscission layer, senesce and drop to ground. Circular dry brown lesions up to 10 mm across also been seen on the bolls. The primary symptoms due to *A. macrospora* on leaves are small pale to brown round or circular spots (0.5-3.0 mm diameter) showing concentric rings with cracked



A typical lesion of Alternaria leaf spot on cotton.



Alternaria blight on whole leaf of cotton (upper surface)



Alternaria blight on whole leaf of cotton (lower surface)



Alternaria blight affected leaf

centre. These spots coalesce to form larger lesions (10mm wide). Severe infection may lead to considerable defoliation. Stem cankers are formed in severe cases. Natural infection of seeds or seed inoculation results in disease on cotyledons.

A. alternata causes usually purple specks or small lesions with purple margins on the leaves and bolls. Drying of leaves and defoliation are associated with severe infection. The pathogen can also infect stems (causing canker) and bolls (resulting in dropping of bolls).

A.gossypina causes yellowing of leaves and defoliation as well as spoilage of cotton bolls and transmitted by dispersal of airborne conidia, usually favored by warm and moist conditions.

6. Myrothecium leaf spot

Myrothecium leaf spot disease is caused by the fungus *Myrothecium roridum*. The disease is sporadic and developments are favored by hot and humid weather. Typical symptoms include lesions in concentric rings with visible sporodochia on the leaves with cracks across the centre of the spot and shotholes. Symptoms are seen on petioles, bracts, leaves and bolls. The characteristic symptoms caused by *M. roridum* are the appearance of circular or oval light ash colored spots with violet to reddish brown margin. Sporodochia are produced in concentric rings and protrude from lower as well as upper surface of leaves. Under severe conditions, the lint gets stained to yellow or light brown. Myrothecium leaf spot has been found to cause 60%



Myrothecium infected cotyledonous leaf



Severely Myrothecium infected plant in field



Myrothecium infected leaf with sporodochia



Myrothecium infected boll

yield losses in cotton (Meyer et al, 2006). The disease was found to be more severe in Madhya Pradesh and based on yield loss experiment at Khandwa during 2008-10, 29.2% loss has been estimated (Monga *et al.*, 2013).

7. Rust

The rust caused by *Phakospora gossypii* (Arth) Hirat. F. occurs sporadically in Tamil Nadu, Andhra Pradesh, Gujarat and Karnataka (Puri *et al.*, 1998). Yield losses ranging from 21.4 to 34.0% were recorded at Dharwad and Guntur due to this disease during recent experiments (Monga *et al.*, 2013). The disease appears late in the season often after the onset of senescence when it may be beneficial in augmenting leaf fall before harvest. However, its early appearance occasionally causes considerable loss by decreasing the photosynthetic area and heavy defoliation. The pathogen initially affects the older leaves and then spreads to the younger ones. Only the uredial stage of the rust occurs in India. Uredial sori appear on the leaves as small (1-3 mm) pinkish brown spots which may coalesce to form larger patches. The uredia are oval to circular on the pedicels and branches. The urediospores are exposed on rupture of the epidermis. The disease is generally observed in the dry season during December-March in India. The severe incidence of rust and leaf spots was noted in northern Karnataka especially during the reproductive phase of crop growth.



Rust infected leaves



Severity of rust infection

8. Boll rot

Fungal boll rot can be caused by many pathogens; though the primary causes are *Colletotrichum gossypii*, *Diplodia gossypina* and *Fusarium moniliforme* (during wet weather) and *Ascochyta gossypii*, *Colletotrichum gossypii* and *Fusarium* spp. (during dry weather). Deformity and immature opening, drying and visible fungal growth on infected bolls are the visible symptoms. Boll rots usually first appear as water-soaked spots in case of bacterial infections. In fungal infections, they are generally covered with a fungus growth. Badly infected bolls may drop from the plant. Some of these fungi invade the cotton bolls directly, whereas others enter through insect wounds or as secondary invaders. Boll rots cause losses by reducing yields, damaging the cotton fibres. Infected seed will result in seedling blights the following season. Rain and high humidity are congenial for boll rot development and increase the incidence of the disease.



Fungal mycelia on infected boll



Dry rot of boll

Bacterial diseases

1. Bacterial leaf blight

Bacterial leaf blight (BLB) also known as angular leaf spot disease is caused by a bacterium *Xanthomonas axonopodis* pv. *malvacearum*. Four phases of the disease viz. seedling phase, Angular leaf spot and vein blight phase, black arm phase and boll rot phase are recognized. The disease is very severe during high humid conditions. Typical symptoms include seedling blight, blackening of stems, leaf spots and boll rot. Symptoms appear as small, angular water soaked spots on the underside of young leaves. Such spots turn brown to black as infection progresses. On stems, the lesions are long and black. On bolls, the spots are sunken and lint



BLB infected seedling



Early symptom of BLB on leaf surface



Severely infected leaf with BLB



BLB infected boll

becomes stained, weak and brittle. Bolls may open prematurely and drop. The disease is having potential threat in all the three cotton growing zones of India.

Viral diseases

1. Cotton leaf curl disease

Cotton leaf curl disease (CLCuD) is one of the most serious virus diseases caused by Gemini virus and transmitted by whitefly (*Bemisia tabaci*). The disease caused massive losses to cotton crop production in India and Pakistan, experienced two epidemics which involved a virus and satellite which are resistance breaking during last two and half decades. The Gemini virus with single stranded circular DNA invaded cotton crop during 1993 in the Indian states of Rajasthan and Punjab adjoining to the border of Pakistan. Within a span of 4-5 years the disease spread in the entire Indian north zone as the highly susceptible varieties of *G. hirsutum* (F-846, RST-9 and HS-6) were being grown in the region. The initiation of disease is characterized by small vein thickening type symptoms on young upper leaves of plants. Other important symptom is upward or downward leaf curling followed by formation of cup shaped leaf laminar outgrowth of veinal tissue on the abaxial side of the leaves. In severe cases reduction of internodal length leading to stunting and reduced flowering/fruitletting was observed. On the undersurface of the leaves, extra leaf-like growth called "enation" can be seen. Severely affected plants due to infection at early stage are stunted and such plants often do not bear any fruiting bodies. Following the reports of breakdown of Cotton leaf curl virus (CLCuV) resistance in popular cotton hybrids in northwestern India during the 2010 season, six strains of CLCuV, including Sri Ganganagar strain isolated from a severely infected CLCuV-resistant variety, were characterized and nucleotide sequences of DNA-A and β DNA components were determined. Sequence comparisons revealed 81–99% and 88.3–92% sequence identity of DNA-A and β DNA, respectively, with known CLCuV sequences. Recombination analysis revealed significant recombination in these six virulent Indian strains showing 25 recombination sites in DNA-A and 11 recombination sites in β DNA. The observed recombination in several regions of DNA-A and β DNA in the potential resistance breaking Sri Ganganagar strain of CLCuV was mapped to the highly virulent Burewala strain and several other strains (Chakrabarty *et al.*, 2011).

Partial sequences of 258 and full-length sequences of 22 virus genomes were determined in a survey conducted in Punjab, Haryana and Rajasthan during cropping seasons of 2009 and 2010. The study indicated that the resistance-breaking cotton leaf curl Burewala virus (CLCuBuV) and its mutant was the dominant virus in many fields of above states (Rajagopalan *et al.*, 2012).

Presently the disease is distributed in India (northwestern states), Pakistan, China and Africa however, it has always been feared that the disease could spread in other cotton growing areas of the world where environmental conditions are congenial for its establishment (Sattar *et al.* 2013). In India it has been perceived that introduction of large number of Bt hybrids since 2005 many of which are highly susceptible to CLCuD aggravated the disease situation to become severe in North Zone. In a recent study Graded Percent Disease Index (5, 10, 20, 40 & 60%) of CLCuD in Bt

cotton (Bio-6488) in Punjab revealed reduction in SCY to the extent of 0.08, 0.29, 14.5, 17.2 & 40.0% respectively.

A large number of host plants of Gemini virus were recorded viz., Sida, country mallow, hibiscus rose, mung, tobacco, tomato, okra, hollyhock, french bean, gwar, *Melilotus indica*, *Ageratum conyzoides*, zinnia, Jungli pudina, Chilli, *Convolvulus arvensis*, *Spinacea sps*, *Solanum nigrum*, *Lanataka camara*, *Chenopodium album*, *Achyranthus aspera*, *Digeria arvensis*, *Capsicum spp.* and *Xanthium strumarium* etc.



CLCuD infected plants shows severe downward curling of leaves



Appearance of multiple lesions on lower surface of leaves



CLCuD infected and healthy plant



Grades Rating Scale For Cotton Leaf Curl Virus Disease

Grades rating scale for CLCuD

2. Tobacco streak virus disease

Tobacco streak virus (TSV) disease is caused by an RNA virus which is transmitted by thrips. This disease is prevalent in the southern part of India but recently reported from Beed, Parbhani, Nanded, and Hingoli districts of Marathwada region with incidence from 10 to 19 per cent on cotton in the month of September to December (Jagtap *et al.*, 2012). Late incidence of TSV was observed in cotton growing districts of Andhra Pradesh except Adilabad and the incidence was highest in Guntur district (3-25%) followed by Warangal (0.1 to 7%) and Karimnagar (up to 5%) during 2011 (CICR, 2012). Symptoms include chlorosis of young leaves at the growing tip, discoloration, bronzing, necrosis, curling of leaves and dwarfing of affected leaves. Severity of TSV infection is dependent of abundance of infected pollen, parthenium population, thrips multiplication and movement on the crop (Prasad Rao, 2009). The virus has several horticultural and fields crops host plants viz. bottle gourd, chilli,

crossandra, cotton, cowpea, cucumber, gherkin, ixora, marigold, mungbean, niger, okra, pumpkin, safflower, sesame, soybean, sunhemp, urdbean, and several weed species in south India (Kumar *et al.*, 2008). The disease has also been reported on sunflower, cotton, chickpea and mung bean in Australia (Sharman *et al.*, 2008).



TSV infected plants showing chlorosis.



Necrosis, curling of leaf and dwarfing

3. Cotton blue disease

Cotton blue disease is caused by cotton leaf roll dwarf virus (CLRDV) (an RNA virus) having positive-sense, single-stranded RNA, transmitted by aphids (*Aphis gossypii*) in a circulative-persistent manner. Cotton plants affected by this disease show stunting, leaf rolling, intense green foliage, vein yellowing, brittleness of leaves,



Infected



Normal

Infected leaves shows shortening of leaf and vein thickening.



CLRDV infected plant showing yellowing of veins



Sterile shoots of an infected plant

reduced flower and boll size and sometimes resulting in sterility of plants. The disease is recently recorded in Maharashtra (Mukherjee *et al.*, 2012).

DISEASE MANAGEMENT

1. Prevention of disease during pre-sowing and at sowing

Field operations/ works to be carried out	Zone
Field should be deeply ploughed and left for solarization to expose the soil borne pathogens	All zones
Fields with long history of Fusarium wilt/root rot should be avoided for growing cotton crop.	All zones
Avoid cultivation of arboreum as well as upland cotton in Fusarium wilt affected areas.	All zones
Adopt crop rotation, avoid ratoon crop, destroy crop residues.	All zones
Avoid cultivation of cotton in fields which were affected with root rot in previous years. Do not allow irrigation water to flow from root rot affected fields to healthy fields. Avoid mono-cropping and cultivation of cucurbitaceous and solanaceous crops in adjoining fields. Intercultivation of Moth bean after each row of cotton for root rot management	All zones
Remove alternate hosts of CLCuD during January-April. Avoid growing of malvaceous crops such as okra, gulkhera, hibiscus and holyhock in CLCuD hot spots. Avoid cultivation of hirsutum cotton in and around citrus orchards for CLCuD. Remove weeds in and around fields. Use of yellow sticky traps for whitefly management. Cultivate virus tolerant varieties/ hybrids in hot spots of CLCuD viz., H-1226, H-1117, HHH-223, HHH-287(Hybrid), F-1861, LHH-144 (Hybrid), RS-875, RS-810, RS-2013, Shresth (CSSH 198), Kalyan (CSHH-238), CSHH 243.	North zone
Opened boll should be picked immediately to avoid seed borne infection	All zones

2. Chemical and biological control of disease

Sl. No.	Name of disease	Cotton growing zones	Duration of occurrence	Control measures
1.	Root rot	Occurs in all zones but severe in irrigated areas of North zone	Seedling to vegetative	Apply ZnSO ₄ @24kg/ha as soil application. Seed treatment with Trichoderma @ 4g/kg seed or Carbendazim 50WP @ 2 g/kg seed or Captan 50WP @ 3g/kg seed or bio-agent <i>Pseudomonas fluorescens</i> @ 10g/ kg seed and chemical Vitavax (carboxin) 200 WP @ 3g/ kg or Soil drenching with Trichoderma @ 10kg/ha mixing with 200kg moist FYM. Spot drenching with Carbendazim 50WP @ 1 g or Thiram 80WP @ 2 g/l water at the base of affected plants as well as surrounding healthy plants.
2.	Fusarium wilt	All cotton growing regions only diploid cottons	Any stage of crop growth	Seed treatment with Carbendazim 50 WP @ 2g/kg seed.
3.	Grey Mildew	Central zone	Fruiting	Foliar spray of Calixin 80EC @1 g or Carbendazim 50 WP @ 1g or Wettable Sulphur 70 % WP@ 2gm or Sulphex 80 WP @ 2.5g /l water as and when symptoms seen.
4.	Alternaria leaf spot	All zones but severe in central and south zone	Vegetative and flowering stage	Seed treatment with <i>Pseudomonas fluorescens</i> PF-1@10g/kg + foliar spray 0.2% Or Spray Mancozeb M-45 @ 2.5 g or Propiconazole 25EC @1ml/l water.
5.	Myrothecium leaf spot	All zones but severe in north zone	Early stage	Spray Copper oxychloride 50 WP@2.5 g or Blitox 50 WP @1g or Captan 83 WP @ 1g or Propiconazole 25EC @1ml/l water.

6.	Rust	Sporadic in central and south Zone	Fruiting	Foliar sprays of Copper oxychloride 50WP @3g or Mancozeb 75 WP @ 2.5g/l or Propiconazole 25EC @1ml/l of water as and when symptoms appeared.
7.	Boll rot	All zones	Fruiting stage	Seed treatment with Carbendazim 50 WP @ 2g/kg seed. Spray Carbendazim 50WP @1g and/or streptocycline 0.1g or copper oxychloride 50 WP @ 3g or Mancozeb 75wp @ 2g or chlorothalonil 75wp @ 2g/l water.
8.	Bacterial leaf blight	All zones	All stage	Soak acid delinted seeds in 0.01 % streptocycline solution for 2-4 hrs. Foliar spray with streptocycline 0.1g + copper oxychloride 50WP @2g /l water.
9.	Cotton leaf curl disease	North zone	Vegetative and flowering stage	Seed treatment with systemic insecticides like Imidacloprid 70WS/ Imidacloprid 600 FS, Thiamethoxam 70 WS for untreated seeds. Spray Neem products, <i>Beauveria bassiana</i> and insecticides like Difenturon 50WP @ 1.2g / Acephate 75SP @1.5g/l to control whitefly-vector of CLCuD.
10.	Tobacco streak virus disease	Andhra Pradesh	Vegetative and fruiting	Control of thrips by spraying Acephate 75SP@ 1.5g/l or Imidacloprid 17.8SL@ 0.3ml/l or Thiamethoxam 25WG @ 0.2g/l or Aetamidrid 20SP@ 0.2ml/l at weekly interval.



Plant parasitic nematodes are foes of cotton crop as they feed on cotton roots and cause reduction in yields necessitating their management by various methods. Nematodes are microscopic, worm-like, animals with life cycle that include one egg stage, four juvenile stages and one adult stage. It has been estimated that about 10% of world agricultural production is lost due to nematode damage. Nematode diseases can be said to be 'Life Style Diseases' of crop plants and have been accentuated due to replacement of traditional agriculture with modern farming practices. Nematode problems surfaced in the Buldhana district of Maharashtra and Khargone district of Madhya Pradesh during 2012-13 crop season where cotton was being cultivated as a pre-seasonal crop with the help of drip irrigation.

1. Recognizing plant damage caused by nematodes

In cotton crop, nematodes feed only on roots. Nematodes suck with a narrow mouth spear called stylet. Nematodes become troublesome only when their population increases beyond a limit. Nematode infested plants do not get enough water and food. Nematode infested plants are thirsty and wilt (loss of turgidity) easily and also look sickly. Symptoms of nematode attack results in weak plant condition, leaf chlorosis, less ability to tolerate adverse conditions, reduced boll size and reduced lint percentage (Dasgupta and Gaur, 1986).

2. Clues for diagnosis of nematode disease

1. Presence of patches of yellowing, unthrifty plants in the field. Weak and unthrifty plants occur in same patch every year and this patch increases gradually in size each year.
2. Unhealthy plants are shorter or lighter in color than healthy plants. Affected plants wilt more readily than healthy looking ones.
3. Root system of these plants gets damaged. Nematode disease is indicated, if roots are unusually small, less in number, have small brown spots or have knots. Irregularly shaped knots or galls formed due to nematodes cannot be separated easily from roots which is indicative of the presence of nematodes (Swarup and Dagupta, 1986, Gokte-Narkhedkar *et al.*, 2004)

3. Symptoms of nematode damage

Visible above ground	Visible below ground
Stunting unthriftness	Root galls or swellings
Yellowing, chlorosis	Short, stubby roots
Mid-day wilting	Lesions or dark spots
Leaf drop	Stunting
Small leaves, small fruits, reduced boll size and reduced lint % leading to reduced yield	Roots appear thick, dirty
Curling/twisting of leaves, stem	White to brown, lemon-shaped, needle head-sized bodies
Patches of poor growth, often oval	Secondary roots nil or absent

4. Sampling the field for detection of nematodes

If nematode disease is suspected in a field, soil should be checked for quantitative and qualitative nematode estimation. Sampling from depth of 8-12 inches is recommended during crop season & deeper sampling is required for fallow soil. For plant parasitic nematodes during crop season rhizosphere samples are taken. Twenty to forty samples should be taken per ha by following w-shaped route. Brief history of crop and disease should accompany these soil samples. Soil samples and plant material should be kept moist and stored in a polythene bag in a cool shady place. For estimation of plant parasitic nematodes the soil sample taken is thoroughly mixed by coning and quartering. After thorough mixing, 250 cc soil should be taken for analysis. Cobb's sieving and decanting technique is used for extraction of nematodes.

5. Root knot nematode *Meloidogyne incognita* (Kofoid and White, 1919) Chitwood, 1949

Root knot nematode *Meloidogyne incognita* (Tylenchida : Heteroderidae) is the predominant nematode species affecting cotton in north Zone and parts of Central

Zone especially in Gujarat. Sandy light soils in north zone favor *M.incognita* multiplication. *M.incognita* infection was reported in a big way on Bt cotton in all the districts of Haryana and Punjab. In Tamil Nadu *M.incognita* infection has been reported on varieties like Suvin and Varalakshmi even in loamy soil. This nematode is also found to be associated with Fusarium wilt of cotton. Out of four races of *M.incognita*, race 3 and 4 infect cotton. Race 3 is recorded from South and Central India whereas in North cotton growing areas race 4 was reported on cotton.

M.incognita are sedentary endoparasites and second stage juveniles are the infective stage. *M.incognita* infection is characterized by galled roots apart from characteristic patchy growth of plants in field. Infected roots are shorter than healthy ones with fewer branch roots and root hairs. Infected plants are stunted, wilt in dry weather, have chlorotic leaves with less flowering and fruiting.

M.incognita has very broad host range and recorded on >700 hosts that include most cultivated crops and ornamentals. It is common in temperate, subtropical and tropical areas. Movement of some cosmopolitan rooted plants across borders and local movement of water, soil and equipments and rooted seedlings are responsible for spread of nematode.



Females of root knot Nematode



Nematode affected plant



Rootknot nematode infected Galled roots



Nematode infested field showing patchy growth

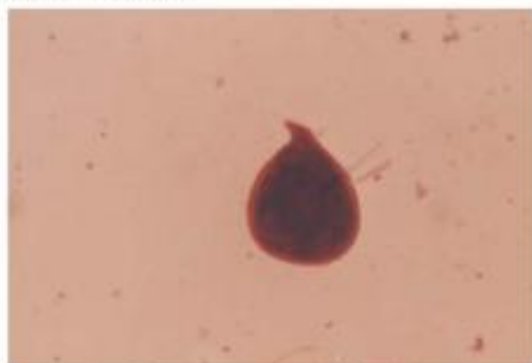
6. Reniform nematode *Rotylenchulus reniformis* Linford and Oliveira, 1940

Reniform nematode *Rotylenchulus reniformis* (Tylenchida : Hoplolaimidae) is

dominant nematode species causing damage to cotton in Central and South India. Yield reduction of 10-15% is common due to reduced boll size and lint percentage. Egg stage, four juvenile stages and one adult stage are the life cycle stages of reniform nematode. Eggs hatch one to two weeks after being laid. The first-stage juvenile molts within the egg, producing the second-stage juvenile (J2) that emerges from the egg. Pericycle and phloem tissues of cotton roots are penetrated by immature female. Adult female is the kidney shaped and hence the name 'Reniform nematode'. The life cycle of this nematode takes around 17-23 days depending on soil temperature. Reniform nematode can survive at least two years in the absence of a host in dry soil through anhydrobiosis, a survival mechanism without water. As the weather warms, nematodes become active and begin feeding and their population starts building up (Varaprasad, 1986; Vadivelu, 1993; Gokte-Narkhedkar, 1999; Gokte-Narkhedkar and Lavhe, 2000).



Reniform nematode on cotton roots



Root knot nematode (female)

7. Estimating root knot nematode infection

Weighted nematode rating (WNR) has been recommended for estimating root knot nematode infection (www.ipm.ucdavis.edu). The technique is based on a subjective rating of the root galling and is particularly useful where cotton is grown again after cotton. Based on field size, cropping history and soil conditions, field is divided into several blocks and 15-20 plants are examined per block. Roots are rated as per rating given below.

Percent roots galled	Weighted rating
0	0
1-25	1
26-50	3
51-75	5
76-100	7

$$\text{WNR} = \frac{\text{Number of root systems} \times \text{weighting factor}}{\text{Maximum weighting factor}} \times 100$$

If WNR is greater than 10, then the chemical treatment is advised. If WNR is between 1 & 10 then soil solarization is recommended. WNR offers advantages of quick results and easy identification of problem areas. Work done at CICR, Nagpur has shown that initial reniform nematode population can be used to estimate crop loss.

Reniform Nematode population per 250 cc soil	Per cent yield loss
10-70	-
71-200	-
201-350	8
351-480	10

8. Strategies for nematode management

Components of strategy for nematode management will depend on whether application is intended for low input rainfed cotton production system or high input irrigated cotton production systems. Monitoring is an assessment of nematode population density in relation to crop development. For accurate diagnosis of nematode disease, it is necessary to collect soil and root samples.

Cultural strategies

- Sanitation-Keep field weed free
- Summer ploughing /soil solarization with polythene cover
- Crop rotation- Include marigold, zinnia, sugarcane, maize, mustard, wheat, barley, jowar, safflower, custard apple, bitter gourd.
- Trap crop- *Crotalaria spectabilis* as trap crop for root knot nematode and uprooted and ploughed in after 30-45 days of sowing.

Biological control

Biological control alone or with chemical: Seed dressing treatment with PGPR (*Gluconacetobacter diazotrophicus* strain 35-47 (CCSHAU, Hisar) along with soil application of Carbofuran@1.0 kg a.i./ha has been found effective against root knot nematode (*Meloidogyne incognita*) infecting cotton.

Egg parasite *Paecilomyces lilacinus* which parasitize the eggs has shown good promise. Soil amendment with non-edible cakes of Neem, Karanj, Mahua etc. have also been recorded effective against root-knot nematodes. Plant extracts toxic to *R. reniformis* include Marigold, Custard apple, Korphad, Bitter gourd, etc.

Chemical

Soil application of Carbofuran 3G 1 kg a.i./ha.



Cultivated cotton crop suffers from several physiological disorders and abiotic stresses that limit productivity. Long duration and indeterminate growth habit exposes the cotton crop to various abiotic stresses such as water deficit or water-logging stress, salinity, high or low temperature, cloudiness, nutrient deficiency etc. These stresses decrease the photosynthesis and the supply of photosynthates. The decreased supply of photosynthate increases square and boll shed and thus reduces the total number of harvestable bolls. Plants with higher boll load are the most sensitive to these stresses due to their increased requirements for photosynthates. The yield loss can be minor to as high as 100% if timely care is not taken. Certain stresses are man-made (like herbicide injury) while others are caused by the natural variations like erratic rainfall and sunny spell. Correct diagnosis of these disorders would, to some extent, help in mitigating the problems.

1. Fruit shedding (abscission)

Fruit shedding could be due to adverse climatic conditions like cloudy weather coupled with excessive vegetative growth. In dense high plant populations, the flowers are buried deep in the canopy; this might result in excessive abscission. Extremely high temperatures also cause square abscission and delayed fruiting.

Management: Application of Auxin/ planofix (Naphthalene Acetic Acid, NAA) 10 to 20 ppm alone or NAA alternated with 1 to 2 % DAP during early flowering stage once or twice as per the requirement was found to be effective in reducing square and boll shedding. It is advisable to apply it either on a cloudy day or late in the evening so as to avoid degradation of chemicals from UV light. Use of growth retardant such as Cycocel, Lihocin and PIX at 50 ppm has also been recommended under irrigated cultivation conditions. Avoid water logging.

2. Square and Boll Drying

In addition to normal abscission of buds and bolls, several genotypes of cotton also lose fruiting forms, which dry up during peak flowering and boll development. This is also common in interspecific hybrids with *G. barbadense* blood. The entire cluster of bolls dries without further growth. Most of the dried bolls remain attached to the plant. The dried bolls become black in color and immature bolls crack up. The impact of boll drying may be reduced with selection of suitable genotypes with lower tendency for drying.



Square drying



Boll drying

3. Leaf Reddening

Leaf reddening is also known as red blight and anthocyanic disease is a physiological disorder and this phenomenon has been reported to occur in American cotton (*G. hirsutum*) ever since it was introduced into India. This disorder is caused by factors such as cloudy weather, water deficit / water logging/ high temperature, nutrient imbalance, genotype etc.

Leaf reddening is initially seen in mature leaves and gradually spreads throughout the canopy. To begin with the leaf margins turn yellow, red colour is developed on the fringes of the leaves or patches or intervascular portions. Later red pigmentation is formed over the whole leaf area. The affected leaves start drying from the edges and prematurely shed. A change in color from green to red may also occur without yellowing. Red leaf generally appeared during flowering or early boll filling stage of growth and arrested further development of bolls, which cracked prematurely. As the red leaf affected crops ceased to grow further, reduction in yield occurs. The use of methomyl in cotton can lead to leaf reddening and systematically damaging the photosynthetic system.

Why more leaf reddening in Bt-cotton?

Under rainfed conditions, cotton is prone to environmental adversities such as cloudy weather, water deficit / water logging/ high temperature, etc. These stresses reduce photosynthesis and availability of photo-assimilates to the developing bolls. Since boll development is more synchronous in Bt cotton and occurs in a shorter time span, any adversity would culminate in physiological disorders like leaf reddening, shedding of fruiting parts and sudden wilt (Hebbar *et al.*, 2007). It is speculated that some of the parents of current Bt cultivars are highly susceptible to physiological disorders.

Management: Foliar application of DAP 2% or Urea 1-2 % (with 15-20 ppm chlormequat chloride and 0.10% citric acid) during boll development stage, adjusting the sowing dates to avoid low night temperature of less than 21° C, preventing water logging, providing protective irrigation to avoid stress, application of MgSO₄ at 20-25 kg/ha to the soil or foliar spray with 1 percent MgSO₄ and 2% urea as soon as the reddening symptoms appear in leaf reduces this disorder.



Leaf reddening



Leaf reddening severity

4. Parawilt/ New wilt

Unlike pathogenic wilt, which occurs in groups of plants in fields, parawilt/new wilt/sudden wilt was noticed to be sporadic (random) in distribution, and does not show discoloration of root vascular bundles. Leaves show wilt like drooping, became chlorotic and turn bronze or red followed by drying and premature abscission of leaves and fruiting parts. Squares and young bolls are shed and immature bolls forcefully open. Wilted plants sometimes gradually recover and produce new flush, however their contribution to yield is negligible. Environmental conditions like high temperature, bright sunlight followed by heavy rainfall were found to favor the occurrence of wilt. It is a disorder in which soil-plant-atmosphere continuum is broken due to adverse environmental factors like flooding or soil saturation or poor root development. Plants at grand growth phase i.e. squaring, flowering and early boll development are more sensitive to wilt in central and south zone. However in north zone parawilt has been observed at peak boll load stage during end of September or early part of October in Bt hybrids.

Management: Proper irrigation: In irrigated areas, over irrigating in the early life of a

crop forces the roots to grow on the surface or remain shallow and can support the plants till flowering. At flowering, the heavy demand for moisture and the tendency to apply more irrigation results in soil anaerobiosis which leads to sudden wilt. Maintaining adequate drainage to avoid water logging of the fields, curtailing excessive vegetative growth (by spaying growth retardant viz., Lihocin, planofix spray @ 50 ppm) and spraying of Potassium nitrate (2.0%) at peak flowering stage 2-3 times at biweekly interval and affected plant with Cobalt chloride 10 ppm within 48 hours of appearance of disease helps in reducing the loss.



Parawilt affected plant at vegetative stage



Parawilt affected plant at boll opening stage

5. Premature senescence

Caused by potassium deficiency, the younger leaves towards the top of the plant turn red and senesce prematurely. Well shaded leaves and branches remain green. Plants with a heavy boll load are affected first while plants with few bolls are usually unaffected. Crops affected by premature senescence are very susceptible to epidemics of *Alternaria* leaf spot if exposed to further periods of wet weather.

6. Fertilizer burn

Root tips are 'pinched off' and sometimes blackened. All roots of affected plants are affected at the same level. If a particular row/rows, are infected in each set across the field then a problem with the fertilizer rig is implied. Fertilizer burn occurs when either solid or liquid fertilizer is placed too close to or directly under, the planting line. Very dry soil conditions between fertilizer application and planting may exacerbate the problem. Care should be taken to place the fertilizer in the vicinity of root zone and not directly on the seed/ roots.

7. Herbicide damage

Herbicide damage is most prevalent during the early stages of growth and symptoms vary considerably according to the type and rate of herbicide used. Symptoms may include yellowing between the veins on cotyledons and lower leaves, stunting and slow growth, root pruning and poor root development, death and defoliation of leaves and cotyledons, seedling death, declining plant stand, etc. Assuming that the rates of application are correct and appropriate for the soil type and assuming the spray equipment is well maintained and calibrated correctly - then - problems are most likely to occur when pre-plant herbicides are incorporated too

deeply or when herbicides applied at planting are washed into the root zone by rain that falls after planting. Damage may be accentuated if the press-wheel on the planter has left a depression along the planting line on top of the bed or if the beds are poorly prepared and loose or have dried considerably prior to the rainfall after planting. Flumeturon causes interveinal bleaching of leaves. Flumeturon in combination with prometryn can damage seed or seedling. Glyphosate injury: High rate of trifluralin may cause swelling of the base of cotton stems and root pruning and burns.

Herbicide 2, 4-Dichlorophenoxy acetic acid (2,4-D) is used in field crops for which cotton is very sensitive. Even a small quantity is sufficient to bring about phytotoxic effects. It is often noticed that a drift of 2, 4-D spray due to wind action from the adjoining areas/fields may cause 2, 4-D syndrome in cotton. Visible symptoms include abnormal changes in morphoform of the plants. The leaves, floral parts and the bracts are malformed. The leaves become narrow and elongated with prominent veins called "monkey palms". The flowers become tubular with elongated floral parts. Spray of 2, 4-D (5 ppm) at flowering led to stem elongation. However, the phytotoxic effects and abnormal changes in leaf and floral parts are accompanied by partial to full loss of apical dominance. As a result, lateral growth arising from the lower nodal positions gives bushy appearance to the plant (Perumal *et al.*, 2006).



2,4-D damage



2,4-D affected field

8. Gall like structures

The stem just above the soil level was transformed into a gall like structure in 45-60 day old plants of some hybrids. It looked like stem weevil damage but exit or entry hole or presence of frass or insect and its feeding was absent. The affected plants wilted and 100% of the plants were affected in the field. This was recorded in Hinganghat. The farmer confirmed spraying of Pendimethalin over the top on cotton after emergence of the cotton crop. The symptoms recorded were typically that of herbicide toxicity.

The gall portion was 2cm long and 7cm in diameter. The surface of the gall was smooth. In some plants white pus like hard spots were seen just above the galls. The roots were clubbed. The tap root was very short 2-3cm in length. Fibrous roots were also short. No leafhoppers injury was recorded on the affected plants. Discolouration of vascular bundles was not seen. When cut open, the galls

presented corky tissue with no bacterial ooze. In some cases the stem split vertically in the portion just above the galls. No boll formation was seen on the affected plant.

Management: A fire fighting exercise involved earthing up to support affected plants and to induce root formation above the galls. Avoid the use of pre emergence herbicides for use over the top on cotton. Use recommended herbicides at the right time and at the recommended dose.



Gall affected plant



Gall formations at the base of the plant

9. Drought

Amongst the various abiotic stresses limiting productivity, drought stress is perhaps the most significant. Depending upon the climate, length of growing period and varietal characteristics, cotton needs around 700-1300 mm rainfall to meet its water requirements. Ideally it needs 2.5 mm/day at the beginning of growth, 5.0 mm/day at flowering initiation, 5.8 mm/day at full bloom, 6-7mm /day at the end of flowering and 4-6 mm/day at boll formation. Under Indian conditions, water requirements ranging from 660-1145 mm have been reported from various regions. In the early vegetative period water requirement is low ranging from 2.5-3.8 mm/day from seedling to first flower. The requirement increases to 7-8 mm/day during peak bloom when the leaf area is maximum and slowly declines to 4-5.0 mm/day during the boll maturation phase (Kulandaivelu, 1980). Water deficit stress may occur in any growth stage-early, mid season or terminal. Maximum yield of cotton under rainfed condition is obtained at 220 mm of available water capacity and on soils with less than 100 mm water storage capacity, rainfed cotton is likely to suffer from terminal drought situation. Water stress at flowering is found to be critical as far as yield realization is concerned.

10. Salinity

Salt affected soils are found in almost all agro-ecological regions. In India, approximately 12 million ha of cultivable land is under salt affected of which 3.6 m ha land is under alkali and rest is under saline soils. The increased area under canal irrigation is further increasing the area under salinity. Common ions contributing to salinity problem are Ca^{++} , Mg^{++} , Na^+ , Cl^- , SO_4^{--} , HCO_3^- and in some instances K^+ and NO_3^- . Salinization and alkalization causes poor plant growth and yield due to 3 major effects viz. water stress caused by salt acting as an osmoticum, specific ion

toxicity and nutrient imbalances.

The salinity effect is stage specific. At germination and emergence it is very sensitive and with advancement of age it could withstand higher salinity levels. Wide species and genotypic variation is seen in salinity tolerance. The mechanism of adaptation to salinity is not very clear, however, there is a direct modification of the influx and/or efflux of ions such as K^+ and Na^+ across the plasma membrane and tonoplast, synthesis of compatible osmotica such as proline, other amino acids, soluble carbohydrates, glycine betaines and modification of membrane proteins have been found to be important components of a salt tolerant phenotype. Thus, tolerant genotypes found to have mechanism for selective absorption of K^+ in saline soils.

11. Water logging

In central India, more than 70 % of the crop is rainfed and often it suffers from water logging during early and mid vegetative stages due to heavy rainfall. Cotton is very sensitive to water logging. Depending on the stage at which water logging occurs, yield reduction may go as high as 10 to 40%, resulting in crores of rupees annual loss to farmers. Water logging for a period of 5 and 15 days reduced the yield at early seedling by 21 % and 52 % and at flowering by 11 % and 37 % respectively while, at later stages water logging did not show significant effect on growth and yield. Thus it is necessary to keep cotton field well drained throughout the season to avoid further physiological disorders.



Plant stand affected due to water logging



Leaf reddening due to water logging



Weeds compete with the cotton crop for nutrition, moisture, light and provide ambient conditions for proliferation of pests. Weed management has assumed serious proportions in recent years with change in rainfall pattern, increasing labourer wages, besides the inevitable high input costs of seed, fertilizer and plant protection chemicals. Prevailing drought situation during June and incessant rains in mid July to August months in black cotton soils of rainfed agriculture affect inter-cultural operations severely. Unabated weed growth forced the farmers to look for herbicides as an alternative to mechanical or hand weeding. Chemical weed management is a recent development in the country. This demand driven need of the farmers attracted many pesticide companies which came forward aggressively for marketing and promotion of herbicides in a big way.

1. Common weed flora observed in cotton:

Grassy weeds: *Phytanum gawat*/ crab grass (*Digitaria ciliaris*), viper grass/*Shimpi* (*Dinebra retroflexa*), dhub/doob/ hariyali (*Cynodon doctylon*) in patches.

Broad leaved weeds: Amaranth/*Kunjar* (*Digera muricata*), Cockscomb (*Celosia argentea*), Prickly chaff flower (*Achyranthes aspera*), Asthma Weed/Common spurge/*Bara dudhi* (*Euphorbia hirta*), spurge (*Euphorbia geniculata*), Indian copperleaf / Deepmal (*Acalypha indica*), Hazardani/ bahupatra/ Bhuimala (*Phyllanthus niruri*), spreading dayflower/*Vinchu* (*Cyanotis axillaris*), Kena/Kana (*Commelina benghalensis*), Gajargawat (*Parthenium hysterophorus*).

Sedges: Nutgrass / Barik moth / Lavvi (*Cyperus rotundus*).

2. Land Preparation

A good seed bed preparation minimizes weed problem to a greater extent whereas neglected fields create problem manifold for years together till weed seed bank get depleted. It is always advisable to follow deep summer ploughing once in 2-3 years immediately after the harvest of crop by mould board plough and subsequently two crosswise harrowing before pre-monsoon showers. This can effectively kill perennial weed seed propagules of *Kans*, *kunda*, *Lavvi* and *Hariyali*. Farmers are advised ploughing and harrowing in such a way that rhizomes and vegetative propagules of weeds must expose to intense summer heat.

3. Pre sowing herbicides

Pre plant foliage (PPF) herbicides such as Ammonium glufosinate (*Basta*), Glyphosate (Roundup), etc., which can be sprayed on the actively growing young weed foliage before crop is planted or in the period between two crops. They can be applied in between rows as lay by application with a protective hood also. They are very effective being systemic in action against perennial weeds like *Kans* (*Sachurum spontaneous*), *Kunda*, *Lavvi*, *Hariyali* except *Bopli* (*Merremia emarginata*). Glyphosate 6ml for annuals and 15 ml for perennial weeds can be applied along with 6-20g ammonium sulphate/l for reducing the pH of hard water. This requires a rain free period of 4-6 hrs on weeds of 3-4 inches height and can effectively kill the weeds within one week. Farmers need to make a choice in case of stale seed bed technique between ploughing and pre-sowing herbicide application depending on the extent of growth and coverage of weeds besides soil slope for controlling soil erosion.

Table 1. Pre sowing herbicides to be applied before or immediately after planting of cotton

Name of the herbicide / group	Trade name	Method of application	Commercial formulation/ ml/ 10 l water	Weed spectrum covered
Glyphosate	Roundup	Pre-sowing foliage spraying	150-250	All except <i>Bopli</i>
Dinitro aniline group	Basalin, Stomp, Prowl, Treflan	Pre sowing incorporation or Pre emergence spraying	70-125	All except <i>Bopli</i> <i>Euphorbea</i>
Chlor acetamide	Alachlor, Butachlor	Pre sowing incorporation or Pre emergence spraying	70-125	All except <i>Bopli</i> very effective against sedges (<i>lavvi</i>)
ALS synthetase	Hit weed	Pre sowing incorporation or Pre / early post emergence spraying	25-35	All except <i>Bopli</i> , <i>Phutane</i> , <i>Kambarmodi vichu kana</i> , <i>sawa</i>
Onion/ Rice herbicides	Oxyflurofen (Goal)	Pre emergence spraying	10-12	All except <i>Bopli</i>
Triazene	Prometryne	Pre plant incorporation or Pre emergence spraying	75g	All weeds but unsuitable for light soils

4. Pre plant herbicide application:

Germinated weeds can be killed by application of Glyphosate 6 ml/l water immediately on or before the day of cotton planting but before cotton germination/emergence. This can kill all the annual and perennial weeds especially if the weed intensity is high (25 weeds/ ft²) and hardy weeds like *Lavvi/Hariyali*. This method has the advantage of saving in sowing time besides least soil disturbance/ erosion on loose soil and conservation of soil moisture for proper germination. Similarly, it can be combined with residual herbicides like Prometryne/ Pendimethalin which can provide 30-45days weed free period. Residual early post emergence weedicide Pyriithiobac Na (Hit weed) also can be sprayed before sowing to 25 days after cotton germination at any time when weeds are about 3-4 inches in height.

5. Pre emergence herbicides

Pre emergence herbicides kill germinating seeds and young seedlings. Generally the site of action is cell division/ elongation/ enlargement of hypocotyl region. Fluchloralin, Pendimethalin, Trifluralin, can control both grasses and broad leaved weeds. Their effectiveness will be maximum when incorporated 1-2 inches in the moist soil by a blade harrow (*bakhar*) after spraying as pre plant incorporation method before sowing or incorporating with 1" interculture in advance planted cotton as Layby method in standing crop of young cotton seedlings. Dinitro aniline herbicides are subjected to volatilization losses and photo decomposition due to UV radiation and therefore need to be carefully incorporated into top moist soil. Other pre emergence herbicides which persist relatively longer even under dry conditions are Prometryne or Butachlor or Oxyfluorfen. These herbicides based weed management systems also require 2-3 intercultures for aeration at 21 days interval and one hand weeding at 30-35 DAS to remove any uncontrolled/ resistant weeds.

After the harvest of previous crop, patches of *Lavvi* and *Hariyali* should be sprayed with systemic herbicides like Glyphosate or for *Lavvi* with Propaquizafop. After 10-12 days, the application may be repeated for the management of remaining weeds.

6. Post emergence weed management:

Annual grasses and perennial weeds *Cyperus rotundus(Lavvi)*, *Cynodon dactylon (Hariyali)*, broad leaf weeds like *Celosia argentea (Cockscomb)* in gravelly fields, *Euphorbia hirta (Doodhi)* in clay soils are the most common weeds observed in Vidarbha. Delay in weed control always delays fertilizer application besides escalating crop losses. Application of post emergence herbicides can reduce hand weeding cost besides preventing crop losses. They would show yellowing and dying symptoms only 7-12 days after application depending upon sunlight intensity.

Post emergence herbicides are mostly foliage active which requires at least 1-4 hrs of rain free period and these herbicides have won the confidence of farmers in recent normal and wet years. Their results are visible after about a week. Quizalofop ethyl (Targa super), Fenoxaprop methyl (Whip super), Propquizafop

(Agil/society) are foliage active graminicides available in the market. They are very effective at a dosage of 2.5-3.5 ml/l water as high volume spray against annual grassy weeds when they are 3-4 inches in height or 20-25 days of age. Pyriithiobac Na is soil and foliage active early post emergence herbicide effective against *Doodhi*, cocks-comb and all grasses except *Phutanegawat* (*Digitaria ciliaris*) and a creeper Bhopli/Undirkani (*Merremia emarginata*) besides *Kambar modi* (*Tridax procumbens*). It was found to be effective in achieving more than 75% weed control despite wet monsoon conditions.

Table 2. Herbicides for post emergence weed control

Name of the herbicide/ group	Trade name	Method of application days after sowing (DAS)	Commercial formulation/ ml/10 l water	Weed spectrum covered
Quizalofop ethyl	Targa/ Targa super	Early Post emergence 20-25	25-35	Graminicide except <i>Hariyali</i>
Fenoxaprop methyl	Whip super	Early Post emergence 20-25	25-35	Graminicide except <i>Hariyali</i>
Propaquizafop	Society/Aegil	Early Post emergence 20-25	25-35	Graminicide effective for <i>Hariyali</i> & <i>Lavvi</i>
Pyriithiobac Na	Hit weed	Early Post emergence 20-25	25-35	Grasses and broad leaf weeds except <i>Hariyali</i> & <i>Lavvi</i>

7. Safe period in rotations and sequential cropping:

Herbicide Hitweed is safe and recommended for cotton and legume inter/ strip crops but Propaquizafop in soybean is useful in sequentially grown wheat. A safe period as per label must be followed. Pendimethalin drift can damage sensitive sorghum. Similarly Pursuit drift can also harm rotational cotton.

8. Precautions

Follow the label instructions carefully and always use protective clothing and goggles. Wash pump and hands with mild soap and warm water. Do not drink or eat with contaminated hands without washing with soap water. Keep away from children and farm animals. Recommended herbicides are relatively safe for humans, fish and down-stream water bodies. Destroy the packing materials/ containers by deeply burying in the soil rather than using domestic/ toilet tumblers. Keep the leaflets/ bills to show to doctor in case of accidents.

Do not experiment with unknown herbicides for tolerance to crops and their growth stages. In case of early post emergence herbicides, target the weeds only at 3-4 inches height. Rotate herbicides of different groups over the years. Always use high

volume knapsack sprayer only with flat fan nozzle for weed control. Higher doses/ less volume of water in motorized knapsack sprayer may damage crop.

9. Herbicide resistant weeds

Repeated application of same herbicide molecules and sub-optimal dosages lead to selection pressure on weed flora and herbicide resistant weed biotypes are evolving such as Isoproturon resistant *Phalaris minor* in north Indian wheat.

10. Herbicide resistant cotton

Recently herbicide resistant cotton (HRC) has attracted farmers' attention and they are waiting for its release especially for ease in weed control. Cotton hybrids/ varieties with tolerance to non selective broad spectrum herbicides Roundup, Ammonium glufosinate and Bromoxynil or their combinations like RR flex, Lybertylink, Glytol, Wide strike, BXN™ have been developed and they are at a pre release stage testing in India. They can be sprayed during germination to flowering stage with respective herbicides once or twice after pre emergence/ post emergence application of herbicides on cotton and can bring more ease in cotton cultivation with respect to weed management even under adverse climatic conditions.

Some of the common weeds in cotton



Kena (*Commelina benghalensis*)



Kunjar (*Digera arvensis*)



Gajargawat (*Parthenium hysterophorus*)



Vinchu (*Cyanotis axillaris*)



Cockscomb (*Celosia argentea*)



Spurge (*Euphorbia geniculata*)



Kambarmodi (*Tridax procumbens*)



Lavvi / Motha (*Cyperus rotundus*)



Asthama weed (*Euphorbia hirta*)



Johnson grass (*Sorghum halepense*)



Undir kani (*Merremia emarginata*)



Bhuimala (*Phyllanthus niruri*)

References

- Aggarwal N. and Neetan (2011) Studies on the compatibility of insecticides to cotton mealybug predator, *Cheilomenes sexmaculata* (Fabricius) http://licac.org/meetings/wcrc/wcrc5/Pdf_File/143.pdf.
- Amarasekare K.G., Mannion C. M. and Epsky N. D. (2009) Efficiency and establishment of three introduced parasitoids of the mealybug *Paracoccus marginatus* (Hemiptera: Pseudococcidae). *Biol. Control*, 51: 91-95.
- Atkinson G.F. (1890) A new *Ramularia* on cotton. *Botanical Gazette*, 15: 166-168.
- Awadallah K.T., Ammar E.D., Tawfik M.F.S. and Rashad A. (1979) Life-history of the white mealybug *Ferrisia virgata* (Ckll.) (Homoptera: Pseudococcidae). *Deut Entomol Z*, 26(1-3): 101-110.
- Ayyar T. V. R. (1932) Insects affecting the cotton plant in India. *Madras Agril Dept Bulletin* 28: 1-28.
- Ayyar, T.V.R. (1929). Notes on some Indian Lepidoptera with abnormal habits. *J. Bomb. Nat. Hist. Soc.*, 33: 668-675.
- Bell, A.A. (1981) Areolate mildew pp.32-35. In: Compendium of Cotton Diseases (Ed. G.M. Watkins), American Phytopathological Society, St. Paul, Minnesota, U.S.A., 87 P.
- Bellows T. S. and Fisher T. W. (1999) *Handbook of biological control: Principles and applications of biological control*. Academic Press. pp. 418
- Ben Dov Y. (2005). The malvastrum mealybug *Ferrisia malvastra* (Hemiptera: Coccoidea: Pseudococcidae), distribution, host plants and pest status in Israel. *Phytoparasitica* 33: 154-156.
- Benzeya S. and Hayat M. (1993) A Review of the Indian species of *Metaphycus* (Hymenoptera: Encyrtidae). *Orient. Insects*, 72: 185-210.
- Bhulya B. A, Chowdhury, S. H. and Kabir, S. M. H. (1997) An annotated list of chalcid parasitoids (Hymenoptera) of coccoidea (Homoptera) on guava in Bangladesh. *Bangladesh J. Zool.*, 25(1): 53-64.
- Bodlah I., Ahmad M., Farooq N. M. and Naeem M. (2010) Record of *Aenasius bambawalei* Hayat, 2009 (Hymenoptera: Encyrtidae), a Parasitoid of *Phenacoccus solenopsis* (Stenomorrhyncha: Pseudococcidae) from Punjab, Pakistan. *Pakistan J. Zool.*, 42(5): 533-536.
- Bozsik A. (2006) Susceptibility of adult *Coccinella septempunctata* (Coleoptera: Coccinellidae) to insecticides with different modes of action. *Pest Manag. Sci.*, 62:651-654.
- Brown J. K. (1992) Virus diseases. pp. 275-329 In R. J. Hillocks (ed.) *Cotton diseases*. CAB International, Wallingford, 415 pp.
- CABI (2002) *Crop Protection Compendium* (2003 edition). Wallingford, UK: CAB International.
- CABI (2013a) <http://www.cabi.org/dmpp/?loadmodule=review&page=4049&reviewid=12939&site=164> accessed on 10 March 2013.
- CABI (2013b) <http://www.cabi.org/dmpp/?page=4049&reviewid=80070&site=164> accessed on 11 March 2013.
- CABI (2013c) <http://www.cabi.org/dmpp/?loadmodule=review&page=4049&reviewid=13145&site=164>.
- Chakrabarty P. K., Sable S. V., Koundal V., Kalbande B., Monga D., Soni R. and Pappu H. R. (2011) Diversity in *Cotton leaf curl virus* (CLCuV) isolates prevalent in northwestern India in light of the breakdown of CLCuV resistance in cotton *Phytopathology* 101:S30 Abstracts presented at the APS-IPPC 2011 Joint Meeting in Honolulu, Hawaii, August 6-10, 2011.
- CICR (2009) Annual Report 2008-2009, Central Institute for Cotton Research, Nagpur.
- CICR (2010) Annual Report 2009-2010, Central Institute for Cotton Research, Nagpur.
- CICR (2011) Vision 2030, Central Institute for Cotton Research, Nagpur.
- CICR (2012) Annual Report 2011-2012, Central Institute for Cotton Research, Nagpur.
- Dasgupta D. R. and Gaur H. S. (1986) The root-knot nematodes, *Meloidogyne* spp. in India. Pp.139-171. In: *Plant parasitic*

nematodes of India- Problems & Progress. (Eds. G. Swarup & D. R. Dasgupta), IARI, New Delhi. P.497.

- Dharajothi B., Surulivelu T., Sonai Rajan T. and Valarmathi R. (2011) First record on the establishment of the parasitoid, *Acerophagus papayae* Noyes & Schauff on *Paracoccus marginatus* Williams and Granara de Willink in cotton. *Karnataka J. Agric. Sci.*, 24(4): 536-537.
- Dhurua S. and Gujar G. T. (2011) Field-evolved resistance to Bt toxin Cry1Ac in the pink bollworm, *Pectinophora gossypiella* (Saunders) (Lepidoptera: Gelechiidae), from India. *Pest. Manag. Sci.*, 67: 898-903. doi: 10.1002/ps.2127.
- DOCS (2013) <http://docs.exdat.com/docs/index-323096.html?page=13> accessed on 30 March 2013.
- Fuchs T. W., Stewart J. W., Minzenmayer R. and Rose M. (1991) First record of *Phenacoccus solenopsis* Tinsley in cultivated cotton in the United States. *Southwest. Entomol.*, 16: 215-221.
- Ghorpade K.D. (1981) Insect prey of Syrphidae (Diptera) from India and neighbouring countries: a review and bibliography. *Trop. Pest Manage.*, 27(1): 62-82.
- Gokhale V.P. and Moghe P.G. (1965) Preliminary investigations on dahiya disease of cotton caused by *Ramularia areola* Atk. in Vidarbha. *Nagpur Agricultural College Magazine*, 38: 27-31.
- Gokte-Narkhedkar N. (1999) Plant parasitic nematodes in cotton hybrids. *Hybrid cotton Newsletter* 8:5.
- Gokte-Narkhedkar N. and Lavhe N.V. (2000) Hybrid -cotton plant parasitic nematodes association in Haryana state. *Hybrid cotton Newsletter* 9: 4-5.
- Gokte-Narkhedkar N., Lavhe N. V., Mukewar P.M. and Khadi B.M. (2009) Optimization of conditions for maximum population index of *Heterorhabditis indica* in modified Wout's substrate for the control of *Helicoverpa armigera*. *Indian J. Plant Prot.*, 37 : 213-2152.
- Gokte-Narkhedkar N., Lavhe N.V. and Mayee C. D. (2001) Entomopathogenic nematodes - Potential agent against American bollworm of cotton (*Helicoverpa armigera*), SAIC Newsletter, 11, p. 4.
- Gokte-Narkhedkar N., Lavhe N.V., Panchbhai P. R., Mukewar P. M. and Singh P. (2005) Development of new substrate for mass multiplication of *Heterorhabditis indica* in the control of cotton bollworm *Helicoverpa armigera*. *International Journal of Nematology*, 15: 191-193.
- Gokte-Narkhedkar N., Lavhe N.V., Panchbhai P.R. and Khadi B. M. (2008) Cottage industry scale *in vivo* production of Entomopathogenic nematode *Heterorhabditis indica* for the control of *Helicoverpa armigera* on cotton. *International Journal of Nematology*, 18 (1): 79-82.
- Gokte-Narkhedkar N., Mukewar P. M. and Mayee C. D. (2004) Plant Parasitic Nematodes of cotton – Farmer's Hidden Enemy, CICR Technical Bulletin No. 27, Central Institute for Cotton Research, Nagpur, 30 P.
- Gokte-Narkhedkar, N., Lavhe N. V., Bambawale O. M. and Khadi B.M. (2006) Entomopathogenic nematode bacterial symbiont-A new management option for management of sucking pests. CICR Newsletter Vol.XXII, No. 1 p.6.
- Gowda C.L.L. (2005) *Helicoverpa* – The global problem. In: Sharma, H.C. (ed.), *Heliothis/Helicoverpa Management: Emerging Trends and Strategies for Future Research*. Oxford and IBH Publishing Co, New Delhi, pp. 1-7.
- Graham, M. W. R. de V. (1969) The Pteromalidae of north-western Europe (Hymenoptera: Chalcidoidea). *Bulletin of the British Museum (Natural History) (Entomology)* Supplement 16: 908pp.
- Gulsar Banu J., Dharajothi, B. and Gokte-Narkhedkar N. (2007) Susceptibility of different stages of cotton bollworm, *Helicoverpa armigera* (Lepidoptera: Noctuidae) to entomopathogenic nematodes. *International Journal of Nematology*, 17(1): 41-45.
- Hayat M. (1998) Aphelinidae of India (Hymenoptera: Chalcidoidea): A taxonomic revision. *Memoirs on Entomology, International*, Vol. 13, Associated Publishers, Florida, USA. 416p.
- Hayat, M. (2006) *Indian Encyrtidae*

- (Hymenoptera: Chalcidoidea). Department of Zoology, Aligarh Muslim University, Aligarh. vii+496 p.
- Hayat, M. and Subba Rao, B. R. (1986) Family Trichogrammatidae. (In: Subba Rao, B.R.; Hayat, M. (Eds) - The Chalcidoidea (Insecta: Hymenoptera) of India and the adjacent countries. Part II.), *Orient. Insects*, 20: 193-208.
 - Hebbar K. B., Rao M.R.K. and Khadi B.M. (2007) Synchronized boll development of Bt cotton hybrids and their physiological consequences. *Curr. Sci.* 93 (5): 693-695.
 - Hodgson C., Abbas G., Arif M.J., Saeed S. and Karar H. (2008) *Phenacoccus solenopsis* Tinsley (Stenomorphina: Coccoidea: Pseudococcidae), an invasive mealybug damaging cotton in Pakistan and India, with a discussion on seasonal morphological variation. *Zootaxa*, 1913: 1-35.
 - Hosagoudar G. N., Chattannavar S. N., and Kulkarni S. (2008) Survey for foliar diseases of Bt Cotton, *Karnataka. J. Agric. Sci.*, 21: 139-140.
 - Huang J., Bin Y. and Zhang J. (2012) Parasitic functional response of *Aenasius bambawalei* Hayat (Hymenoptera: Encyrtidae) to *Phenacoccus solenopsis* Tinsley (Hemiptera: Pseudococcidae). *Acta Entomol. Sin.*, 55(12): 1418-1423.
 - ICAR (2011). Available at <http://www.icar.org.in/en/node/2283>
 - Ignoffo C. M., Garcia C., Hostetter D. L. and Pinnel R. E. (1977) Laboratory studies of the entomopathogenic fungus, *Nomuraea rileyi*; Soil borne contaminants of soybean seedlings and dispersal of diseased larvae of *Trichoplusia ni*. *J. Invertebr. Pathol.*, 29: 147-152.
 - Ignoffo, C. M. (1981) The fungus *Nomuraea rileyi* as a microbial insecticide. In: *Microbial Control of Pests and Plant Diseases 1970-80*. BURGESS, H. D. Ed., Academic Press, New York, pp. 513-536.
 - Jagtap G.P., Jadhav T. H. and Utpal D. (2012) Occurrence, distribution and survey of Tobacco streak virus (TSV) of cotton. *Scient. J. Crop Sci.*, 1(1) 16-19.
 - Jalali M. A., Tirry L. and Clerq P. D. (2009) Food consumption and immature growth of *Adalia bipunctata* (Coleoptera: Coccinellidae) on a natural prey and a factitious food. *Europ. J. Entomol.*, 106:193-198.
 - Jeyaparvathi S, Baskaran S. and Bakavathiappan G. (2013) Biological control potential of spiders on the selected cotton pests. *Intl. J. Pharm. Life Sci.*, 4(4): 2568-2572.
 - Kareim A.I. (1998) Searching rate and potential of some natural enemies as bio-control agent against the *Bemisia tabaci* (Homoptera: Aleyrodidae). *J. Appl. Entomol.*, 122: 487-492
 - Kennedy J. S., Day M. F. and Eastop V. F. (1962) A Conspectus of Aphids as Vectors of Plant Viruses, pp. 114. London: Commonwealth Institute of Entomology.
 - Khan M., Kelly D., Hickman M., Mensah R., Brier H. and Wilson L. (2004) Mirid ecology in Australia. *CRS Research Rev* 15.
 - Kranthi K.R. and Russell D.A. (2009) Changing trends in cotton pest management In *Integrated Pest Management: Innovation-Development Process* (Ed Dr. Rajinder Peshin and A.K. Dhawan) Springer Netherlands, p 499-541
 - Kranthi K.R., Jadhav D.R., Kranthi, S. Wanjari R.R. Ali S.S. and Russell D.A. (2002) Insecticide resistance in five major insect pests of cotton in India. *Crop Prot.*, 21(6):449-460.
 - Krishna Ayyar P. N. and Margabandhu V. (1941) Biology of the Cotton Stem-Weevil, *Pempherulus affinis*, Fst., under controlled physical Conditions. *Bull. Entomol. Res.*, 32(01): 61-82.
 - Kumar Rishi, Nagrare V. S., Nitharwal M., Swami D. and Prasad Y. G. (2013) Within-plant distribution of an invasive mealybug, *Phenacoccus solenopsis*, and associated losses in cotton. *Phytoparasitica*, Published online on 7 November 2013, DOI 10.1007/s12600-013-0361-6.
 - Kumar P.L., Prasada Rao R.D.V.J., Reddy A.S., Madhavi K. J., Anitha K. and Waliyar F. (2008) Emergence and spread of tobacco streak virus menace in India and control strategies. *Indian J. Plant Prot.*, 36(1): 1- 8.
 - Lalitha, C., Muralikrishna, T., Sravani, S. and Devaki, K. (2012) *In vitro* evaluation of native *Bacillus thuringiensis* isolates against II instar

- Spodoptera litura* (Fabricius). *Annals Plant Prot. Sci.*, 20 (1): 88-90.
- Lingappa, S. and Patil, R.K. (2002) *Nomuraea rileyi* – A Potential mycoinsecticide. University of Agricultural Sciences, Dharwad, 30 p.
 - Malaise M. and Ravensberg W. J. (1992) The biology of glasshouse pests and their natural enemies: knowing and recognising. Berkelen Rodenrijs, The Netherlands.
 - Malpatil M.B., Dunn K.L. and Smith D. (2000) An Illustrated Guide to the parasitic wasps associated with citrus scale insects and mealybugs in Australia. Natural Resources and Environment / HRDC, Agriculture Victoria, Australia. 152 p.
 - Mani M. (1989) A review of the pink mealybug - *Maconellicoccus hirsutus* (Green). *Insect Sci. Applic.* 10:157-167.
 - Mani M. (1990) The grapevine mealybug. *Ind. Hortic.*, 35:28-29.
 - Mani M. and Krishnamoorthy A. (2008) Biological suppression of the mealybugs *Planococcus citri* (Risso), *Ferrisia virgata* (Cockerell) and *Nipaecoccus viridis* (Newstead) on pummelo with *Cryptolaemus montrouzieri* Mulsant in India. *J. Bio. Cont.*, 22:169-172.
 - Manjula K., Arjuna Rao, P. and Nagalingam, B. (2004) Record of *Nomuraea rileyi* (Farlow) Samson on *Helicoverpa armigera* Hubner in kharif Groundnut. *Indian J. Plant Prot.*, 32:125.
 - Manjula K., Nagalingam B. and Arjuna Rao P. (2003) Occurrence of *Nomuraea rileyi* on *Spodoptera litura* and *Helicoverpa armigera* in Guntur District of Andhra Pradesh. *Annals Plant Prot. Sci.*, 11: 224- 227.
 - Mayne W.W. 1953. *Cryptolaemus montrouzieri* Mulsant in South India. *Nature* 172: 85.
 - Meyer M.C., Silva J.C., Lorena Maia G., Bueno C.J. and Luiz de Souza, N. (2006) Myrothecium leaf spot of cotton caused by *Myrothecium roridum*. *Summa phytopatologica*, 32(4) 390-393.
 - Mohan S. and Nandini S. (2011) Survival of pink bollworm, *Pectinophora gossypiella* (Saunders) in Bt and Non Bt Cotton in normal and late sowing with a special emphasize to avoid population pressure. http://www.icac.org/meetings/wrcr/wrcr5/Proceeding_PDF/229.pdf
 - Monga D. and Raj S. (1994) Cultural and pathogenic variation in the isolates of *Rhizoctonia* spp. causing root rot of cotton, *Indian Phytopath.*, 47:217-225.
 - Monga D., Sree Lakshmi B. and Prakash A. H. (2013) Crop losses due to important cotton diseases. Central Institute for Cotton research, Regional Station, Sirsa p 23.
 - Mukherjee A.K., Chahande P.R., Meshram M.K. and Kranthi K.R. (2012) First report of Polorovirus of the family Luteoviridae infecting cotton in India. *New Disease Reports* 25, 22. [doi:10.5197/j.2044-0588.2012.025.022]
 - Murugesan N. and Kavitha A. (2010) Host plant resistance in cotton accessions to the leafhopper *Amrasca devastans* (Distant). *J. Biopest.*, 3:526-533.
 - Murugesan N., Balakrishnan N., Vimala R., Shunmugavalli N. and Ramalingam A. (2010) Impact of time of sowing and *in situ* sun drying of cotton stalks and on the management of cotton stem weevil, *Pempherulus affinis* Faust. *J. Biopest.*, 3(2): 420 - 422
 - Nagrare V. S., Kranthi S., Kumar Rishi, Dharajothi B., Amutha M., Deshmukh A. J., Bisane K. D. and Kranthi K. R. (2011) Compendium of Cotton Mealybugs, CICR, Nagpur, 52 p.
 - Nagrare V.S., Kranthi S., Biradar V.K., Zade N.N., Sangode V., Kakde G., Shukla R.M., Shivare D. Khadi B.M. and Kranthi K.R. (2009) Widespread infestation of the exotic mealybug species, *Phenacoccus solenopsis* Tinsley (Hemiptera: Pseudococcidae), on cotton in India. *Bull. Entomol. Res.*, 99: 537-541.
 - NAIP (2012) (<http://www.naip.icar.org.in/pmts/images/Component04.pdf>).
 - NBAll (2013a) <http://www.nbaii.res.in/Featured%20insects/Cheilomenes.htm> accessed on 27 April 2013.
 - NBAll (2013b) http://www.nbaii.res.in/Featured%20insects/Nephus_regularis.htm. Accessed on 27 April 2013.
 - Noyes J. (2013) Universal Chalcidoidea Database. <http://www.nhm.ac.uk/research-curation/research/projects/chalcidoids/>
 - Oliveira M. R. V., Henneberry T. J. and

- Anderson P. (2001) History, current status and collaborative research projects for *Bemisia tabaci*, *Crop Prot.*, 20:709-723
- Patil B. V., Bheemanna M., Patil S. B., Udikeri S. S., and Hosaman I. (2006) A Record of mirid bug *Creontiades biseratense* (Distant) on cotton from Karnataka., India. *Insect Environ.*, 11: 176-177.
 - Patil R.K., Lingappa S., Hiremath R.V. and Hiremath I.G. (2003) Seasonal incidence of *Nomuraea rileyi* (Farlow) Samson on *Spodoptera litura* (F) in groundnut ecosystem. *J. Entomol. Res.*, 22: 109-113.
 - Patil S. B. (2003) Studies on management of cotton pink bollworm *Pectinophora gossypiella* (Saunders) (Lepidoptera: Gelechiidae). Ph. D. Thesis, Univ. Agric. Sci., Dharwad (India).
 - Perumal N.K., Hebbar K.B., Rao M.R.K. and Singh P. (2006) Physiological disorders in cotton CICR Technical Bulletin No: 28. Available at http://www.cicr.org.in/pdf/physiological_disorder.pdf
 - Prabhakar M., Prasad Y.G., Thirupathi M., Sreedevi G., Dharajothi B. and Venkateswarlu B. (2011) Use of ground based hyperspectral remote sensing for detection of stress in cotton caused by leafhopper (Hemiptera: Cicadellidae). *Comput. Electron. Agr.*, 79:189-198
 - Prasada Rao R.D.V.J., Jyotsna M. K., Reddy A. S., Varaprasad K. S., Nigam, S. N. and Kumar P. L. (2009) *Indian J. Plant Prot.*, 37 (1 & 2):196-198.
 - Puri S.N., Sharma O.P., Murthy K.S. and Sheo Raj (1998) Handbook on Diagnosis and Integrated Management of Cotton Pests. National Centre for Integrated Pest Management, Pusa Campus, New Delhi, India, pp.52-53.
 - Puttarudriah M. and Channabasavanna G.P. (1957) Notes on some predators of mealybugs (Coccidae: Hemiptera). *The Mysore Agricultural Journal* 32(1): 4-19.
 - Rajagopalan P. A., Naik A., Katturi P., Kurulekar M., Kankanallu R. S. and Anandalakshmi R. (2012) Dominance of resistance-breaking cotton leaf curl Burewala virus (CLCuBuV) in northwestern India. *Arch Virol.* 157(5):855-68.
 - Rashid, M. M. U., Khattak M. K., Abdullah K., Amir M., Tariq M. and Nawaz S. (2012) Feeding potential of *Chrysoperla carnea* and *Cryptolaemus montrouzieri* on cotton mealybug, *Phenacoccus solenopsis*. *J. Anim. Plant Sci.*, 22(3): 639-643.
 - Ravi P. R. and Patil B. V. (2008) Biology of Mirid bug, *Creontiades biseratense* (Distant) (Hemiptera: Miridae) on Bt Cotton. *Karnataka J. Agric. Sci.*, 21(2): 234-236.
 - Rawat R. R. and Jakhmola S. S. (1970) Bionomics of the mango-Coccid (*Rastrococcus iceryoides* Green; Homoptera: Coccidae). *Indian J. Agric. Sci.* 40(2):140-144.
 - Rawat R. R. and Modi B. N. (1969) Studies on *Nephus regularis* (Coleoptera: Coccinellidae) as a Predator of the Striped Mealybug in Madhya Pradesh (India) *Ann. Entomol. Soc. Am.* 62(5): 953-956.
 - Razaq M., Aslam M. and Suhail A. (2006) Synergism of pyrethroids with piperonyl butoxide (PBO) in jassid, *Amrasca devastans* (Dist.) (Homoptera: Cicadellidae) from Pakistan. *Pak. Entomol.*, 28(2): 51-56.
 - Sammaiah C., Laxma P. and Samatha C. (2012) Study on infestation of cotton insect stainers on Bt-cotton and non Bt-cotton in Warangal, Andhra Pradesh. *Intl.J. Environ. Sci.*, 3(3): 1155-1160
 - Sangitrao C.S., Moghe P. G., Dahule K. K., Shivankar S.K. and Wangikar P.D. (1993) Compendium of grey mildew of cotton. PDKV, Akola, India, 66 P.
 - Sattar M. N. Kvarnheden A., Saeed M, and Briddon R. W. (2013) Cotton leaf curl disease – an emerging threat to cotton production worldwide. *J. Gen Virol vir.0.049627-0*; online published on January 16, 2013.
 - Sekhon B. S. and Varma G. C. (1983) Parasitoids of *Pectinophora gossypiella* (Lepidoptera: Gelechiidae) and *Earias* spp. (Lepidoptera: Noctuidae) in the Punjab. *Entomophaga*, 28: 45-54.
 - SEL (2013) <http://www.sel.barc.usda.gov/catalogs/pseudoco/Ferrisiamalvastra.htm> accessed on 30 Mar 2013.
 - Selvaraju N. G. and Sakthivel N. (2011) Host plants of papaya mealybug (*Paracoccus marginatus* Williams and Granara de Willink.) in Tamil Nadu. *Karnataka J. Agric. Sci.*, 24 (4):567-569.
 - Rashid, M. M. U., Khattak M. K., Abdullah K.,

- Seni A. and Sahoo A.K. (2012b) Biology of Mealybug, *Rastrococcus iceryoides* (Green) on Citrus, *Annals Plant Prot. Sci.* 20(1): 72-74.
- Seni, A. and Sahoo A.K. (2012a) Biology of the parthenium infested mealybug (*Ferrisia consobrina* Williams and Watson) (Pseudococcidae: Hemiptera). *J. Crop Weed*, 8(1): 193-194.
- Sharman M., Thomas J. E. and Persley D.M. (2008) First report of Tobacco streak virus in sunflower (*Helianthus annuus*), cotton (*Gossypium hirsutum*), chickpea (*Cicer arietinum*) and mungbean (*Vigna radiata*) in Australia. *Australas. Plant Dis. Notes.*, 3: 27-29.
- Shivankar S. K. and Wangikar P.D. (1992) Estimation of crop losses due to grey mildew disease of cotton caused by *Ramularia areola*. *Indian Phytopath.*, 45: 74-76.
- Shivanna B.K., Nagaraja D.N., Manjunatha M., Gayathridevi S., Pradeep S. and Girijesh G.K. (2009) Bionomics of cotton leafhopper *Amrasca biguttula biguttula* on transgenic Bt cotton. *Karnataka J. Agric. Sci.*, 22:538-540.
- Singh S. P. (2001) *Augmentative biocontrol in India*. In S.P. Singh S.T., Murphy and C.R. Ballal (eds) *Augmentative Biocontrol*. CABI Bioscience, UK and Project Directorate of Biological Control, Bangalore, pp. 1-20.
- Singh S. P. (2003) Role of predators and parasitoids in biological control of crop pests. In: O. Koul, G. S. Dhaliwal, S. S. Marwaha and J. K. Arora (eds) *Biopesticides and pest management*. Vol. 1. Campus Books International, New Delhi, pp. 196-221.
- Solangi G. S. and Mahmood R. (2011) Biology, host specificity and population trends of *Aenasius bambawalei* Hayat and its role in controlling mealybug, *Phenacoccus solenopsis* Tinsley at Tandojam Sindh, http://www.icac.org/tis/regional_networks/asian_network/meeting_5/documents/papers/PapSolangiGS-et_al.pdf.
- Srikumar K. K. and Bhat P. S. (2012) Field survey and comparative biology of tea mosquito bug (*Helopeltis* spp.) on cashew (*Anacardium occidentale* Linn.). *J. Cell Anim. Bio.* 6(14): 200-206.
- Srinivasan K. V. (1994) *Cotton Diseases*, Indian Society for Cotton Improvement, Bombay. Pp 311.
- Sugonjaev E. S. and Gordh, G. (1981) Taxonomy and trophic relations of encyrtids of the genus *Encyrtus* Latr. (Hymenoptera, Encyrtidae) of Holarctic region. *Entomologicheskoe Obozrenie*, 60(4): 883-897.
- Sunderland K. D., Fracer A. M. and Dixon A. F. G. (1986) Field and laboratory studies on money spiders (Linyphiidae) as predators of cereal aphids. *J. Appl. Ecol.*, 23: 433 - 447.
- Surulivelu T. and Dharajothi, B. (2006) Mirid Bug, *Creontiodes biseratense* (Distant) damage on Cotton in Coimbatore. www.cicr.org.in.
- Swarup G. and Dagupta D. R. (1986) *Plant parasitic nematodes of India- Problems & Progress*. (Eds. G.Swarup & D.R.Dasgupta), IARI, New Delhi. P497.
- Tanwar R.K., Jeyakumar P. and Vennila S. (2010) Papaya mealybug and its management strategies, Technical Bulletin 22, National Centre for Integrated Pest Management, New Delhi, pp 22.
- Tanwar R.K., Jeyakumar P., Singh A., Jafri A.A. and Bambawale O.M. (2011) Survey for cotton mealybug, *Phenacoccus solenopsis* (Tinsley) and its natural enemies. *J. Environ. Biol.*, 32: 381-384
- Thomas A. and Ramamurthy V. V. (2011) on the diagnostics of mealybug occurring on cotton, spherical mealybug *Nipaecoccus virilise* (Newstead) (Hemiptera: Pseudococcidae) *Mum. Ent. Zool.* 6(1): 455 - 459.
- Thorvilson H.G., Pedigo L.P. and Lewis L.C., (1985) The potential of alfalfa fields as early season nurseries for natural enemies of *Plathypena scabra* (F.) (Lepidoptera: Noctuidae). *J. Kans. Entomol. Soc.*, 58: 597-604.
- Tinsley J. D. (1898) Notes on Coccidae, with descriptions of new species. *Can. Entomol.*, 30: 317-320.
- Udikeri S. S. (2008) Mirid menace: an emerging potential sucking pest problem in cotton. *The ICAC reporter*, 26(4): 15.
- Udikeri S. S., Kranthi K. R., Patil S. B., Modagi S.A and Vandal N.B. (2010) Bionomics of mirid bug *Creontiodes*

- biseratense* (Distant) and oviposition pattern in Bt cotton, *Karnataka J. Agric. Sci.*, 23(1): 153-156.
- Udikeri S.S., Kranthi K.R., Patil S.B. and Khadi B.M (2011) Emerging Pests of Bt Cotton and Dynamics of Insect Pests in Different Events of Bt Cotton. Available at http://www.icac.org/tis/regional_networks/asian_network/meeting_5/documents/papers/PapUdikeriS.pdf
 - Vadivelu S. (1993) Nematode problems of Cotton . pp. 157-161 In. Hand book of Economic Nematology Eds.R.S.Singh & K.Sitaramaiah, Cosmo Publications, New Delhi.336P.
 - Van Heerden D. (1992) The Biology of *Palexorist alaxa* (Curran) (Diptera: Tachinidae), An Internal Larval Parasitoid of *Heliothis Armigera* (Hobner) (Lepidoptera: Noctuidae). M Sc Thesis Rhodes University, Grahamstown, South Africa.
 - Varaprasad K.S.(1986) *Rotylenchulus reniformis* Linford and Oliveira, 1940-A Comparative account of Systematics, Biology & Management. Pp 194-210. In: *Plant parasitic nematodes of India- Problems & Progress.* (Eds. G.Swarup & D.R.Dasgupta), IARI, New Delhi. P497.
 - Venkatesan T., Baby Nesil Liz, Jalali S. K., Shylesha A. N. and Rabindra R. J. (2011) Characterization and identification of *Acerophagus papayae* Noyes and Schauff (Hymenoptera: Encyrtidae), an introduced parasitoid of papaya mealybug, *Paracoccus marginatus* Williams and Granara de Willink through DNA barcode. *J.Biol.Control*, 25(1): 11- 13.
 - Vennila S., Agarwal M, Nagrare V.S., Singh J., and Prasad Y.G. (2012) Description, damage, scenario, weather based prediction and management of mirid bugs (*Campylomma livida* – Miridae: Hemiptera) on rainfed cotton of Central India. Paper presented at the International Conference on Plant Health Management for Food Security, held during 28-30 November 2012at Hyderabad.
 - Vennila S., Biradar V. K., Sabesh M. and Bambawale O. M. (2007a) Know your cotton insect pest APHID, Crop protection folder series 1 of 11, CICR, Nagpur.
 - Vennila S., Biradar V. K., Sabesh M. and Bambawale O. M. (2007b) Know your cotton insect pest THRIPS , Crop protection folder series 3 of 11, CICR, Nagpur.
 - Vennila S., Biradar V. K., Sabesh M. and Bambawale O. M. (2007c) Know your cotton insect pest WHITEFLIES, Crop protection folder series 4of 11, CICR, Nagpur.
 - Vennila S., Biradar V. K., Sabesh M. and Bambawale O. M. (2007d) Know your cotton insect pest AMERICAN BOLLWORM, Crop protection folder series 6 of 11, CICR, Nagpur.
 - Vennila S., Biradar V. K., Sabesh M.and Bambawale O. M. (2007e) Know your cotton insect pest SPOTTED and SPINY BOLLWORM, Crop protection folder series 5 of 11, CICR, Nagpur.
 - Vennila S., Biradar V. K., Sabesh M.and Bambawale O. M. (2007f) Know your cotton insect pest STAINER (red and dusky cotton bugs), Crop protection folder series 9 of 11, CICR, Nagpur.
 - Vennila S., Deshmukh A.J., Pinjarkar D., Agarwal M., Ramamurthy V.V., Joshi S., Kranthi K.R. and Bambawale O.M. (2010). Biology of the mealybug, *Phenacoccus solenopsis* on cotton in the laboratory. *J. Insect Sci.* 10:1-9 available online: insectscience.org/10.1155.
 - Vennila S., Prasad Y.G., Prabhakar M., Kumar Rishi, Nagrare V., Amutha M., Dharajyothi B., Agarwal M., Sreedevi G., Venkateswarlu B., Kranthi K.R. and Bambawale O.M. (2011). Spatio-temporal Distribution of Host Plants of Cotton Mealybug, *Phenacoccus solenopsis* Tinsley in India. *Technical Bulletin No. 26*, National Centre for Integrated Pest Management, New Delhi P 50.
 - Wang Y., Watson G. W. and Zhang R. (2010) The potential distribution of an invasive mealybug *Phenacoccus solenopsis* and its threat to cotton in Asia. *Agr. Forest Entomol.*, DOI: 10.1111/j.1461-9563.2010.00490.x
 - www.ipm.ucdavis.edu UC IPM Pest Management Guidelines: Cotton,UC ANR Publication 3444 Nematodes by P. A. Roberts, D. J. Munier & P. B. Goodell.
 - You L. S., Lei Run-Hua, Jiang Jie-Xian, Bo Lian-Yang and Xiao Zhi-Shu (2002) Bionomic of *Campoletis chlorideae* (Hym: Ichneumonidae) as a Parasitoid of the cotton bollworm *Helicoverpa armigera* (Lep: Noctuidae), *Insect Science*, 9(3):29–37.