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A Treatise on Mealybugs of Central Indian Cotton Production System

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National Centre for Integrated Pest Management
New Delhi

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Research into Decision Support System for Management of
Insect Pests of Major Rice and Cotton Based Cropping Systems

National Centre for Integrated Pest Management
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Top row

Hibiscus sabdariffa
Hibiscus rosa-sinensis
Central Indian cotton cropping system
Euphorbia hirta
Cajanus cajan

Bottom row

Gossypium hirsutum
Cardiospermum helicacabum
Malvastrum coramandelinum
Parthenium hysterophorus
Lycopercicon esculentum

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FOREWORD

Invasive pests need special attention in view of their unanticipated development over space and time causing yield and revenue losses to the crops of agriculture and horticulture. Majority of pest problems of Indian agriculture are addressed only when the insects attain pest status over large areas. The lack of preparedness in the absence of immediate basic information on species diversity, host range and biology often results in adoption of management strategies followed elsewhere, and more often it involves the selection of insecticide control options preempting the possible and successful suppression or eradication by natural biotic and abiotic environmental forces.

Mealybugs were never a menace on field crops in recent times, but *Phenacoccus solenopsis* assumed significance on cotton between 2007 and 2008 seasons in Northern States, in particular and across the country, in general. Simultaneous efforts by researchers and governmental agencies brought forth information on host range, availability of natural enemies and adopted successful awareness campaigns especially in Punjab on its management. While information on mealybugs has been published as research papers, advisory folders, leaflets, posters and videos from Northern States during the past two years, comprehensive assemblage of details on mealybugs on various aspects has been lacking from other parts of the country.

The launch of NAIP on development of Decision Support System for management of insect pests of cotton considered mealybug as one of the major problems and developed a frame work for studies of diversity and biology, besides quantification of host range and natural control by natural enemies. Wider host range *vis-à-vis* limited severity across rainfed cotton of Central India was obvious. It is interesting to note the possibility of weed host management and natural biological control keeping check of population of *P. solenopsis*. With presence of species specific parasitoid *Aenasius bambawalei,* measures of mealybug management should be biological over chemical.

Strategies of conservation of parasitoids should be central to mealybug management prior to use of insecticides. This bulletin on “A Treatise on Mealybugs of Central Indian Cotton Production System” presents the details of species identity, seasonality and severity of occurrence, spread and host range, biology and estimates of yield loss suggesting the needful management strategies that would prove useful for all stakeholders of plant protection.

The research team of the institute deserves commendations in bringing out comprehensive knowledge-rich technical bulletin for all stake-holders who have anything to do with this mealybug.

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For an entomologist nothing satisfies except an opportunity to gain knowledge of an insect in full right from its diversity, distribution, abundance, host range, biology and its natural biotic and abiotic forces in the crop production environment of interest before embarking on to investigating an effective management strategy using chemicals. I am privileged to be associated with mealybugs between 2008 and 2009 seasons at Central India, wherein the focus was on quick understanding of potential of mealybugs as pest of cotton and immediate steps to be taken to limit its spread and severity.

The vision of National Agricultural Innovation Project (NAIP) advisory committee members Dr. T.M. Manjunath and Dr. S. Lingappa to recommend mealybugs as one of the target insects under the project on "Decision Support System for the Management of Insect Pests of Major Rice and Cotton based Cropping Systems" allowed me to use the resources of time, manpower and money especially for mealybugs. Effort of the Consortium lead centre, Central Research Institute for Dryland Agriculture, Hyderabad deserves our sincere appreciations for the forceful encouragement to bring forth the bulletin to serve as a base line for Central Indian cotton production system.

I am most grateful to Dr. K.R. Kranthi, Director, Central Institute for Cotton Research, under whose able guidance, the research work furnished in the bulletin was carried out at Nagpur. Nonetheless I am equally beholden to Dr. O.M. Bambawale, Director, and National Centre for Integrated Pest Management, who provided the choice and support to publish the research work from New Delhi.

The identification services of mealybugs and their parasitoids provided by Dr. V.V. Ramamurthy and S. Joshi of IARI, New Delhi and of host plant species by Dr. P.C. Pagar, College of Agriculture (PDKV), Nagpur are thankfully acknowledged. The genuine and tireless assistance offered by A. Deshmukh, D. Pinjarkar, M. Wagde, Bhongle, Hari Dange, Pancham Rawat, Asmita, Archana, Ranjana and Sanjay is recognized with gratitude and fond memories.

I thankfully acknowledge the financial assistance by World Bank through Indian Council of Agricultural Research, New Delhi to carry out the present study as a part of National Agricultural Innovation Project (NAIP/DSS/C 2046) at Central Institute for Cotton Research, Nagpur.

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A Treatise on
Mealybugs of Central Indian Cotton Production System

INTRODUCTION

Of the 3.5 m ha cotton area in Maharashtra, 98.2% is rainfed and more than 80% is cultivated with Bt cotton. Effective suppression of bollworms by Bt cotton has not only led to increased production and productivity, but has decreased the insecticide use on the crop. However, Bt cotton yield potential is limited by sap feeders such as jassids (*Amrasca devastans* Distant), thrips (*Thrips tabaci* Lindeman) and mirids (*Campylomma livida* Reuter) and management of sap feeders has become essential to realize yield potential of Bt transgenics. Since 2008-09, mealybugs too have emerged as potential threat to cotton production at Central India. Widespread infestation of the mealybug, *Phenacoccus solenopsis* Tinsley (Hemiptera: Pseudococcidae) in India occurred over large areas of different cropping systems across the three cotton growing regions, attaining pest status during 2008. *P. solenopsis* has been the topic of research for insect taxonomists and applied entomologists in India due to its invasiveness, rapid spread, morphological and biological variations and the need for establishing an effective control strategy. Crops of different categories *viz.,* food, fibre, fruit, ornamental, plantation and vegetable crops besides weeds were infested by *P. solenopsis.* As the insect had started its appearance from North cotton growing areas, the search for its presence and abundance at Central zone could be planned timely and systematically, although the severity was in pockets of Central India. Given the changing climate and cultivation profile of cotton, it becomes imminent to analyze at once the basics of insect pest to put its management in proper perspective. This bulletin presents the exclusive studies carried out on mealybugs in general and of *P. solenopsis*, in particular at Central India to facilitate the availability of comprehensive information for the interest groups of the nation.

DIVERSITY AND ABUNDANCE

Diversity of mealybugs (Pseudococcidae: Hemiptera) in cotton production system of Central India indicated three species *viz., Phenacoccus solenopsis* Tinsley, *Maconellicoccus hirsutus* (Green), *Nipaecoccus viridis* Newstead on cotton and four more species *viz., Coccidohystrix insolita* Green, *Ferrisia virgata* Cockrell, *Drosicha mangiferae* Green and *Ferrisia malvastra* (Mc Daniel) on pigeonpea, guava, mango

and a weed host *Sonchus oleraceus*, respectively. *P. solenopsis* was the dominant species among all mealybugs over large areas followed by *M. hirsutus*. The occurrence of *N. viridis* was sketchy and less frequent on cotton or any other plants including weeds. *P. solenopsis* attained pest status in pockets of cotton growing districts of Central India during 2007 with sporadic and limited incidence of *M. hirsutus*.

Mealybugs of Central Indian Cotton Production System

P. solenopsis

M. hirsutus

N. viridis

C. insolita

F. virgata

D. mangiferae

GEOGRAPHICAL DISTRIBUTION AND PEST STATUS OF *P. SOLENOPSIS*

P. solenopsis has a wider geographical distribution with its origin in Central America (Williams & Granara de Willink, 1992) followed by reports of the Caribbean and Ecuador (Ben-Dov, 1994), Chile (Larrain, 2002), Argentina (Granara de Willink, 2003), Brazil (Mark & Gullan, 2005). *P. solenopsis* has been described as a serious cum invasive pest of cotton in Pakistan and India (Hodgson *et al*., 2008) and on *Hibiscus rosa-sinensis* in Nigeria (Akintola & Ande, 2008). Latest report on the invasiveness of *P. solenopsis* has been from the Eastern region of Sri Lanka (Prishanthini & Laxmi, 2009) on ornamentals, vegetable crops and weeds, and in China (Wang *et al.,* 2009; Wu & Zhang, 2009) on cotton. *P. solenopsis* appeared on cotton in Pakistan during 2005 and attained pest status in cotton growing areas of Punjab and Sindh provinces. In India, occurrence, severity and epidemic forecast of mealybugs on cotton were made at Gujarat in respect of 2004-05, 2005-06 and 2006-07 crop seasons, however the species identity got documented as *P. solenopsis* in a workshop at National Center for Integrated Pest Management (NCIPM), New Delhi in January 2008 (Jhala & Bharpoda, 2008a) followed by its publication in Uttar Pradesh Journal of Zoology (Jhala *et al*., 2008). However, Bambawale (2008 a & b) reported the occurrence of *P. solenopsis* a decade ago from non cotton growing areas of Uttar Pradesh, Madhya Pradesh and Karnataka States of India and described it as a non-invasive pest. An elaborate and comparative study of few species of *Phenacoccus* including the Indian and Pakistan specimens, and details on the existence of seasonal morphological variations in *P. solenopsis* by Hodgson *et al.* (2008) provided strong footing and support on species identity of mealybugs in India. Widespread infestation of *P. solenopsis* and economic damage to cotton across nine cotton growing States of the country *viz.,* Punjab, Haryana, Rajasthan, Gujarat, Madhya Pradesh, Maharashtra, Andhra Pradesh, Karnataka and Tamil Nadu during 2008-09 crop season necessitated a national level consultation at Central Institute for Cotton Research (CICR), Nagpur towards formulation of strategies for its management (Dharajyothi *et al*., 2008; Dhawan, 2008; Jhala & Bharpoda, 2008 b & c; Suresh & Kavitha, 2008). Survey across 47 locations of the country between months of late 2007 and early 2008 established the predominance of *P. solenopsis* (Nagrare *et al*., 2009) in India.

ASSESSMENT OF INCIDENCE AND SEVERITY

The infestation based on presence or absence of mealy bugs and the severity using zero to four scale of infestation *viz.,* 0 – No mealybug; 1 – Scattered appearance of few mealybugs on the plant; 2 – Severe incidence of mealybug on any one branch

of the plant; 3 – Severe incidence of mealybug on more than one branch or half portion of the plant and 4 – Severe incidence of mealybug on the whole plant was recorded. Study on sample size indicated the importance of locating the source of mealybug infestation first, and sampling that accounts field areas largely parallel to the infestation source. While sample sizes of 25 to 50 plants per acre are sufficient in fields with known source of infestation such as roadside weeds and water channels, 100 plants per acre have to be sampled in clean field where prior knowledge of mealybug infestation is not available (Anonymous, 2009).

SEASONAL INCIDENCE AND SEVERITY ON COTTON

Mealybug severity on cotton crop at the cotton + pigeonpea cropping system of Central India was in traces and sporadic during 2008-09 crop season to study their field level dynamics at experimental and farmer fields. However, surveys revealed their occurrence as random across locations on diverse hosts. The different cultivars of cotton within a given area suffered more due to *P. solenopsis* than other host plants be it weeds/vegetables/other field crops. It is to be noted that the cotton plants in glass and net houses suffered heavily even during the off season of cotton crop during 2008 indicating the preference for cotton among all other hosts. Highly reduced incidence and severity of *P. solenopsis* on Bt cotton in cotton based cropping system of Central zone during 2009-10 was noted over previous cotton season. The mean incidence and severity relations were rather negative due to disjunctive occurrence of *P. solenopsis* over space and time (Table 1).

Table: 1. Incidence-severity relations of *P. solenopsis* at cotton+pigeonpea cropping system

Mealybug	Incidence (%)	Severity	% G4 Plants
Incidence (%)	1		
Severity	-0.24 ^{NS}	1	
% G4 Plants	0.63**	0.09 ^{NS}	1

(data sets of 2008; n=11; ^{NS}: non significant; ** : significant at $p \leq 0.01$)

Scale of severity did not have any significant effect on plants reaching Grade 4. However the extreme severity had significantly increased the incidence indicating the effective dispersal of *P. solenopsis* after the whole plant succumbs to its attack.

SPREAD POTENTIAL

Potential of *P. solenopsis* for natural spread can be described as limited as well as unlimited- limited from the perspective of the fact that the species is actively mobile only in crawler stage; unlimited considering the evidences that the species has dispersed beyond its centre of origin across continents quite faster. Utilizing the natural occurrence of *P. solenopsis* and *M. hirsutus* in the unprotected cultivated fields of sole crop of cotton *Gossypium hirsutum* L. at experimental station, the spread pattern in terms of levels and severity of infestation was studied from the foci of onset of the insects on a single plant over a period of two months between September and November. While the spread was measured in terms of incidence, severity index (cumulative total of grades/ number of infested plants) was used to measure the intensity of attack. It was found that the spread and severity of infestation was higher for *M. hirsutus* over *P. solenopsis*. While the rate of spread of infestation as well as severity was similar for both the species till November first week, infestation declined in both cases in the following week (Fig. 1 and 2).

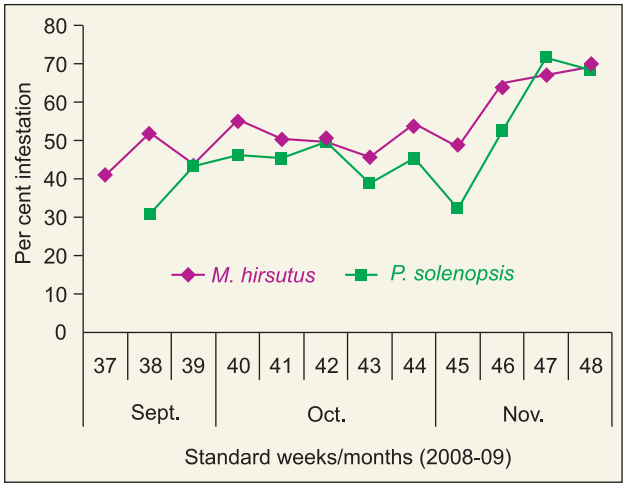

Fig. 1. Dynamics of infestation spread of *P. solenopsis* and *M. hirsutus* from source spots

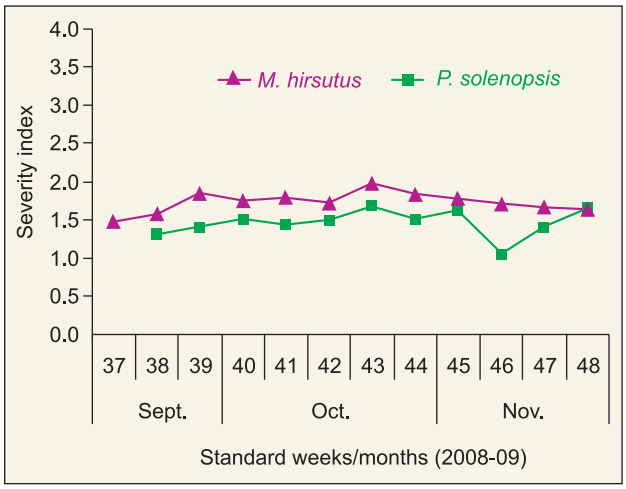

Fig. 2. Dynamics of severity of *P. solenopsis* and *M. hirsutus* from source spots

Although the mean severity of *M. hirsutus* was constant over the season, fluctuations in *P. solenopsis* severity was noted with sharp decline during mid

November in response to occasional showers only to increase faster at maturity stage of the crop. Given the occurrence of both the species simultaneously on cotton, the rate of spread of incidence and severity were higher for *M. hirsutus* than *P. solenopsis* with no biotic environmental resistance in terms of parasitoids and predators.

YIELD LOSS ESTIMATES

At the Central zone, with the cotton + pigeonpea cropping system, the potential reduction in yield levels in respect of Grade 1, Grade 2, Grade 3 and Grade 4 severity of mealybug infestation was estimated to be 36.5, 46.6, 63.5 and 76.4% for *M. hirsutus* and 2.4, 31.5, 39.9 and 43.9 % for *P. solenopsis* (Fig. 3) indicating the potential of former over the later species. Since the appearance of Grade 1 symptom due to *M. hirsutus* occurred always with the presence of reporducing females alongwith crawlers on the plants, the yield losses had been higher over *P. solenopsis*. Nevertheless, fewer number of crawlers of *P. solenopsis* alone led to Grade 1 that caused insignificant yield loss in cotton. In the North zone, the reduction yield of cotton plants due to *P. solenopsis* was estimated to be 14.6 and 53.6 per cent at first and fourth grade mealybug infestation levels, respectively (Anonymous, 2009).

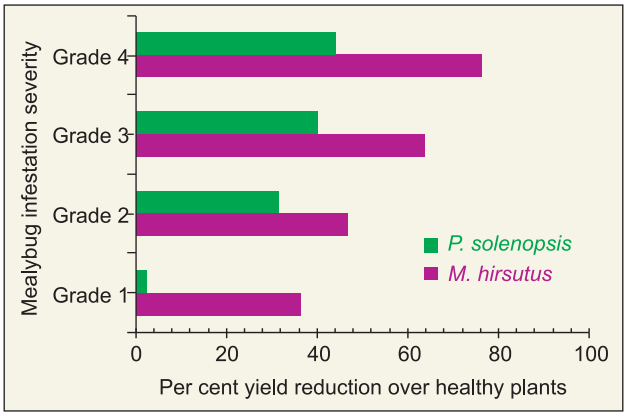

Fig. 3. Yield loss due to mealybugs

Development of symptoms among infested cotton plants occur much faster with *M. hirsutus* over *P. solenopsis*. While Grade 2 severity of *M. hirsutus* could cause severe stunting of 30-40 days old cotton crop, only extreme severity (Grade 4) of *P. solenopsis* affected the crop growth symptomatically. In addition, the highly aggregative and intense within plant attribution of *M. hirsutus* at severity levels of Grade 3 and 4 had caused higher yield losses over *P. solenopsis*. However, the diverse and higher levels of parasitisation of *M. hirsutus* in Central cotton production system had kept its occurrence sporadic and limited.

HOST RANGE

P. solenopsis is a polyphagous pest feeding and reproducing on a wide range of plants. Literature survey on pest status of *P. solenopsis* indicated severe economic damage to wide range of vegetables, horticultural and field crops. *P. solenopsis* infesting cotton and 29 other host plant species of 13 families were reported in the U.S (Fuchs *et al.,* 1991). Twenty two host plants were studied for the prevalence of cotton mealybug, *P. solenopsis* between December 2006 to November 2007 in the area around Faisalabad (Aheer *et al.,* 2009), and maximum prevalence of mealybug was observed on china rose (*Hibiscus chinensis*) followed by okra (*Abelmoschus esculentus*). Arif *et al*. (2009) recorded 154 plant species belonging to 53 families with preference to plants from Malvaceaea, Solanaceae, Ficoidae, Amaranthaceae, Asteraceae, Convolvulaceae, Euphorbiaceae, Verbanaceae and Zygophyllaceae as host plants of *P. solenopsis* from the cotton agrosystem of Punjab (Pakistan). Economical damage was observed on cotton, brinjal, okra, tomato, sesame, sunflower and china rose with plant death in severe conditions. *P. solenopsis* has been reported from a maximum of 183 plants in 52 families by Ben-Dov *et al*. (2009). A total of 55 host-plants in 18 families were reported by Abbas *et al*. (2010) from Punjab and Sindh regions of Pakistan. In Sri Lanka, primary host of *P. solenopsis* was reported to be shoe flower, *Hibiscus rosa sinensis* and other crops *viz.,* okra, brinjal, tomato, chillies, amaranthus, sunflower, some ornamental and weed hosts from home gardens also were reported as host plants (Prishanthini and Vinobaba, 2009). In India, although the economic damage was noticed on the dominantly cultivated up land cotton *Gossypium hirsutum* L. and its hybrids followed by *desi* cotton *G. arboreum*, *P. solenopsis* has several host plants belonging to various categories *viz.,* cereals, pulses, oilseeds, vegetables, ornamentals, weeds and fruits.

Gradual build up of population of an invasive/new insect largely on a specific host plant would indicate the insect species' feeding and breeding preference, and the plant host becomes the main host. However, accounts of *P. solenopsis* suddenly reaching damaging populations simultaneously on many fields of Northern cotton growing States, led us to investigate the alternate host plants for *P. solenopsis* within cotton production system of Central India. Since the study of host range and spatial and temporal preference for hosts constitute foundation for understanding the source and time of spread of the pest, instant emphasis was given to document the host range of *P. solenopsis* elaborately at Central India, despite its disjunctive occurrence as pest on cotton. Moreover, identification of the host plants of *P. solenopsis* playing a significant role in spread during growing season and carry-over during off season

would guide to formulate cultural control strategies, such that the pest can be managed with minimum use of insecticides. The dominance of host plants in the agroecosystem was also measured in terms of nominal scale of vegetation *viz.,* low, medium and high based on their presence in 10 sqm area surveyed randomly at ten different spots. Frequent occurrence of a host plant species with a mean of more than five plants per 100 sqm was categorised to have high vegetation. Number of plants of a host species ranging between two and five, and at least one among ten survey spots of 10 sqm constituted medium and low degree of vegetation, respectively. Stages of host plants found on more than one occasion at successive time periods of survey alone were assessed for dominance in addition to severity due to mealybugs.

PROFILE OF HOST PLANTS OF *P. SOLENOPSIS*

Field surveys for host range of *P. solenopsis* under the rainfed cotton production system covering details of the severity and time of incidence, association of parasitoid and ant species with regard to *P. solenopsis* besides distribution of host plants in terms of their dominance and spatial distribution are furnished and summarised in Annexure 1 and Table 2, respectively.

Table: 2. Host profile of *P. solenopsis* at Central Indian cotton production system

Details of plant species	Total no. of hosts	No. of weed hosts
Host plant species	84*	60**
Hosts of cotton season	19	15
Off season hosts	46	30
Hosts prevalent in both cotton and off seasons	19	15
G4 hosts of cotton season	08	06
G4 hosts of off season	09	07
G4 hosts prevalent in both cotton and off seasons	06	05
Hosts with high dominance	22	16
Hosts with medium dominance	32	20
Hosts with low dominance	30	24
Hosts of mealybug-ant association	26	16
Hosts of mealybug-parasitoid association	10	05

* Total number of host families = 28 ; ** Total number of weed host families = 22

Alternate hosts of *P. solenopsis* in the present context included the plants that served as breeding hosts wherein both adults (females) and crawlers were found at the time of survey. Exclusive Grade 1 host plants can also be considered as incidental hosts at present, although their potential role in pest spread cannot be ruled out. Association of *P. solenopsis* with ants and the hosts on which parasitized mealybugs were also noted with confirmations done during subsequent surveys.

Family: Malvaceae

Abelmoschus esculentus

Abutilon indicum

Azanza lampas

Hibiscus sabdariffa

G. hirsutum

G. arboreum

Hibiscus rosa-sinensis

Malvastrum coramandelinum

DIVERSITY OF HOSTS *VIS A VIS* SEVERITY OF *P. SOLENOPSIS*

A total record of 84 host plants across 28 families (Fig. 4) with majority of them (60 across 22 families) belonging to weeds was recorded.

Eleven host plants each from Asteraceae, Leguminaceae and Malvaceae, six from Solanaceae and four each from Amaranthaceae, Euphorbiaceae and

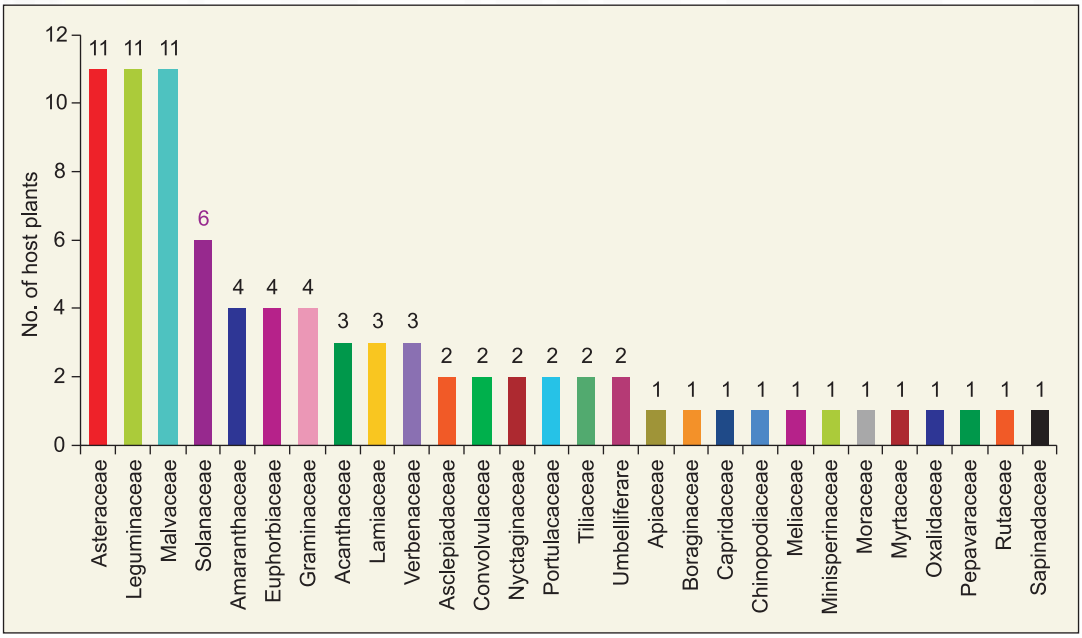

Fig. 4. Families of host plants of *P. solenopsis*

Graminaceae were recorded. Six families with two and twelve families with single plant species served as hosts. Weeds dominated as major hosts of *P. solenopsis.* Plant species from families *viz.,* Asteraceae (Compositae), Leguminaceae, Malvaceae and Solanaceae constituted nearly 50% of the host plants of *P. solenopsis*.

Eighty four host plants belonged to eight categories of plant kingdom *viz.,* field crops, fruits, medicinal plants, ornamentals, plantations, spices, vegetables and weeds. Sixty weeds among 22 families served as host plants for *P. solenopsis*. Seven vegetable crops [brinjal (*Solanum melongena*), tomato (*Lycopercicon esculentum*), chillies (*Capsicum annuum*), mesta (*Hibiscus sabdariffa*), okra (*Abelmoschus esculentus*), spinach (*Beta vulgaris var bengalensis*) and field beans (*Lablab purpureus*)], four each from plantations [bodhi tree (*Ficus religiosa*), neem (*Azadirachta indica*), horse tamarind (*Leucaena leucocephala*) and Flame of forest (*Butea monosperma*)], field crops [upland and desi cotton (*Gossypium hirsutum* and *Gossypium arboreum*), pigeonpea (*Cajanus cajan*) and chickpea (*Cicer arietinum*)] and ornamentals [marigold (*Tagetus sp.*), fire cracker plant (*Crossandra infundibuliformis*), shoe flower (*Hibiscus rosa-sinensis*) and sonkadi (*Vicoa indica*)] besides two each of spices [bishop's weed (*Trachyspermum amoni*) and funnel (*Foeniculum vulgare*)] and medicinal plants [Indian bassil (*Ocium sanctum*) and curry

leaves (*Murrya koenigii*)] were attacked by *P. solenopsis*. Guava (*Psidium guajava*) was the only fruit crop infested by *P. solenopsis* (Fig. 5).

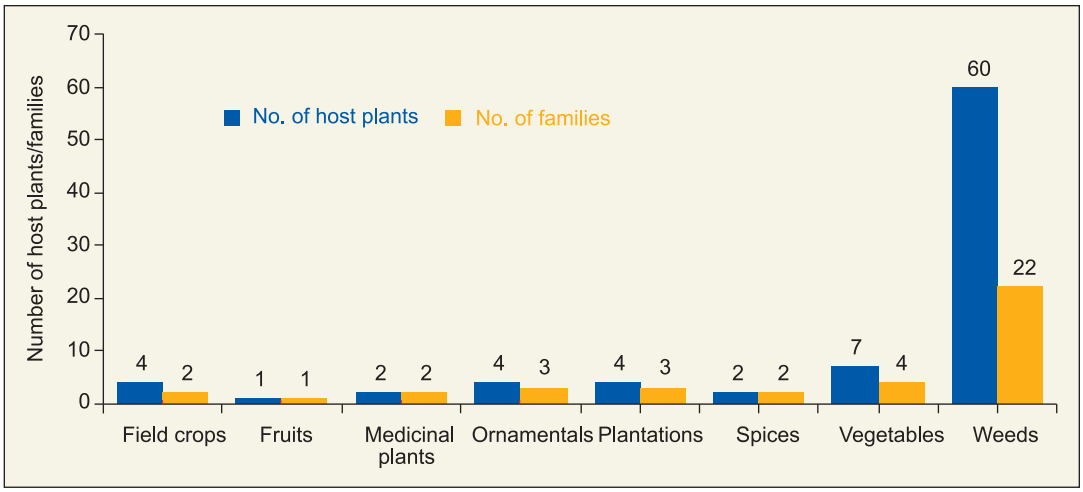

Fig. 5. Category of host plants of *P. solenopsis*

While many host plants of *P. solenopsis* could delay the outbreaks on any one crop plant, the numerous and wide ranging hosts would facilitate spatial spread of the insect. Thus the host plant diversity for *P. solenopsis* can be a boon and bane in rainfed Bt cotton production system. Numerous and diverse groups of host plants had facilitated rapid spatial spread of the insect. However, wider host range of *P. solenopsis* could have played a significant role in delaying the outbreaks on any crop in the production system as was evident from the disjunctive occurrence of the pest on cotton at Central India, unlike Northern States. Occurrence of *P. solenopsis* on large number of weed hosts signified the importance of weed management in containing the spread of the pest.

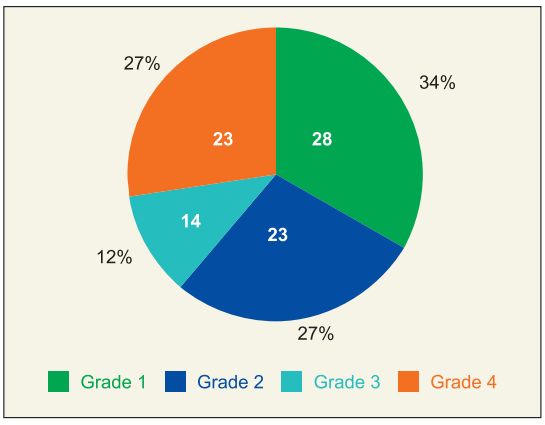

Fig. 6. Severity of *P. solenopsis* across host plants

Twenty eight, 19, 14 and 23 host plants represented 34, 27, 12 and 27% of *P. solenopsis* severity with Grade 1, Grade 2, Grade 3 and Grade 4, respectively (Fig. 6). Host plants from

Family: Asteraceae

Gaillardia pulchella

Parthenium hysterophorus

Sonchus sarvensis

Sonchus oleraceus

Tridax procumbens

Vicoa indica

Xanthium strumarium

Family: Leguminaceae

Butea monosperma

Cajanus cajan

Cicer arietinum

Leucaena leucocephala

Desmodium diffusum

Malvaceae (6), Asteraceae (4), Euphorbiaceae (3), Solanaceae (2), Amaranthaceae (2), Convolvulaceae (1), Nyctaginaceae (1), Portulacaceae (1), Umbelliferae (1), Verbenaceae (1) and Sapinadaceae (1) showed maximum severity of Grade 4. While nine families contained host plants with Grade 2 and Grade 3 severity of *P. solenopsis*, nineteen families had host plants with Grade 1 severity. All grades of severity (Grade 1 to 4) were noted only with Asteraceae. Varying maximum severity levels among host plants within the same family were evident at least in 15 of the families indicating the preference for breeding by *P. solenopsis*. It was a general observation that the maximum severity levels coincided with the flowering and maturity stages of the host plants. Maximum severity of *P. solenopsis* observed was of the order Malvaceae > Asteraceae > Euphorbiaceae > Solanaceae > Amaranthaceae > Verbanaceae > Nyctaginaceae > Portulacaceae > Umbellifereae > Sapinadaceae (Fig. 7).

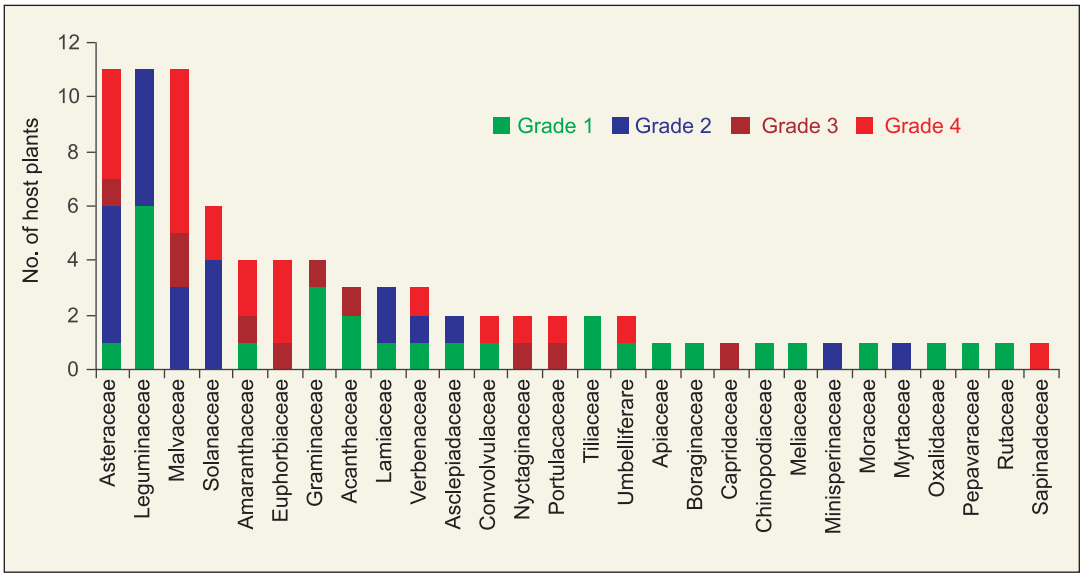

Fig. 7. *P. solenopsis* severity across families of host plants

SEASONALITY OF HOST PLANTS *VIS A VIS* SEVERITY OF *P. SOLENOPSIS*

The host plants from Solanaceae (6), Acanthaceae (3), Convolvulaceae (2) and Nyctaginaceae (2) were exclusive to off season, in addition to single plant species from eight families *viz.,* Apiaceae, Boraginaceae, Capridiaceae, Meliaceae, Minisperinaceae, Moraceae, Myrtaceae and Oxalidaceae. Six hosts from five families were exclusive to both cotton as well as off seasons among which only *Cardiospermum helicacabum* of Sapinadaceae had the highest severity of Grade 4 (Fig. 8).

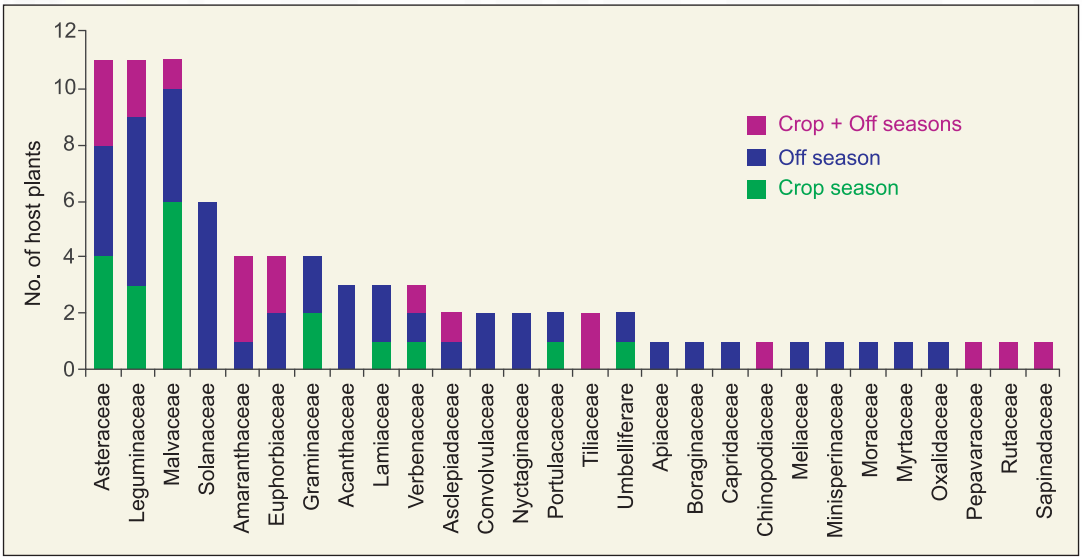

Fig. 8. Seasonality of host plants of *P. solenopsis*

There was no family with host plant (s) exclusive to cotton season indicating the *P. solenopsis* adaptability to diverse hosts even in the presence of larger areas of cotton in the production system. *P. solenopsis* was found multiplying exclusively on 19 and 46 host plants during the cotton growing and off seasons, respectively.

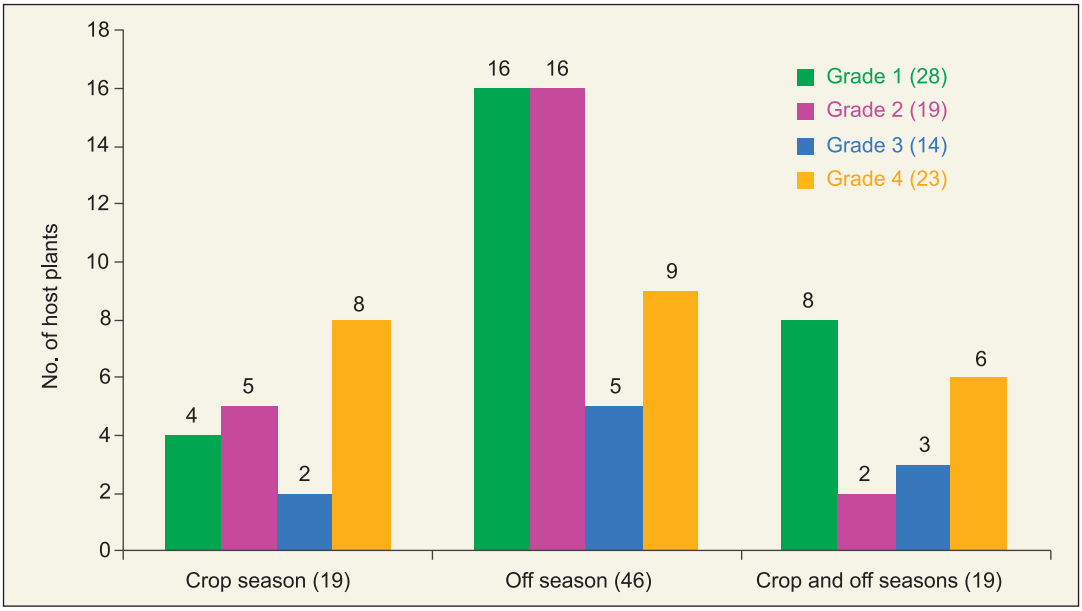

Fig. 9. Seasonal severity of *P. solenopsis* on host plants

Additional nineteen hosts had *P. solenopsis* population during growing as well as off seasons, exclusively. More than double the number (46) of off over the growing season (19) hosts indicated diverse carry over hosts between cotton seasons (Fig. 9).

Family: Solanaceae

Capsicum annuum

Lycopercicon esculentum

Physalis minima

Solanum melongena

Solanum nigrum

Family: Euphorbiaceae

Euphorbia hirta

Phyllanthus niruri

Family: Amaranthaceae

Amaranthus viridis

Alteranthera triandra

Family: Graminaceae

Dinebra sp.

Cynodon dactylon

Panicum javanicum

Family: Laminaceae

Leucas urticaefolia

Ocimum sanctum

Weed hosts (30) of off season were higher over hosts of cotton season (15) by 50% (refer Annexure 1). In general, number of host plants was higher under each severity scale during off season. Lower severity of Grade 1 was across maximum hosts during off season followed by crop cum off seasons (8) and crop season alone (4). Severity of *P. solenopsis* with intermediary scale *viz*., Grade 2 and 3 was also variable across seasons, being higher during off season (27) over crop (7) or crop cum off seasons (5). Out of eight host plants that had extreme severity during cotton growing season, four belonged to Malvaceae (*Azanza lampas, Malvastrum coramandelinum, Hibiscus sabdariffa* and *Gossypium hirsutum*) and one each were from Asteraceae (*Lactuca runcinata*), Portulacaceae (*Portulaca quadrifida*), Umbelliferae (*Centella asiatica*), and Verbanaceae (*Tectona grandis*). Off season development of *P. solenopsis* to Grade 4 was observed on nine hosts. Two hosts each from Asteraceae (*Vicoa indica* and *Taraxacum officinale*), Euphorbiaceae (*Euphorbia geniculata* and *Acalypha indica*) and Solanaceae (*Lycopercicon esculentum* and *Physalis minima*), and one each from Convolvulaceae (*Convolvulus arvensis*), Malvaceae (*Abutilon indicum*) and Nyctaginaceae (*Boerhavia diffusa*) effectively supported *P. solenopsis* development exclusively during off season.

A total of six hosts occurring through growing as well as off seasons *viz., Achyranthus aspara* and *Amaranthus viridis* (Amaranthaceae), *Parthenium hysterophorus* (Asteraceae), *Phyllanthus niruri* (Euphorbiaceae), *Hibiscus rosa-sinensis* (Malvaceae) and *Cardiospermum helicacabum* (Sapinadaceae) supported development of *P. solenopsis* up to extreme severity (Grade 4). *Alternanthera triandra* (Amaranthaceae), *Tridax procumbens* (Asteraceae) and *Euphorbia hirta* (Euphorbiaceae) had a maximum of Grade 3 from among growing + off season hosts. Extremely higher number of host plants with lower severity Grade 1 and Grade 2 during off season were over the crop as well as crop and off season hosts put together indicated that the additional hosts of off season play a transient but critical role towards spatial and temporal sustenance of *P. solenopsis* between crop seasons.

DOMINANCE OF HOST PLANTS *VIS A VIS* SEVERITY OF *P. SOLENOPSIS*

Since infestation depends not only on the presence of hosts but also on their dominance, besides preference by *P. solenopsis,* the severity in relation to degree of dominance of host plants was analysed. Nearly 26, 38 and 36 % of host plants belonged to high, medium and low dominance category of vegetation in the cotton production system (Fig. 10).

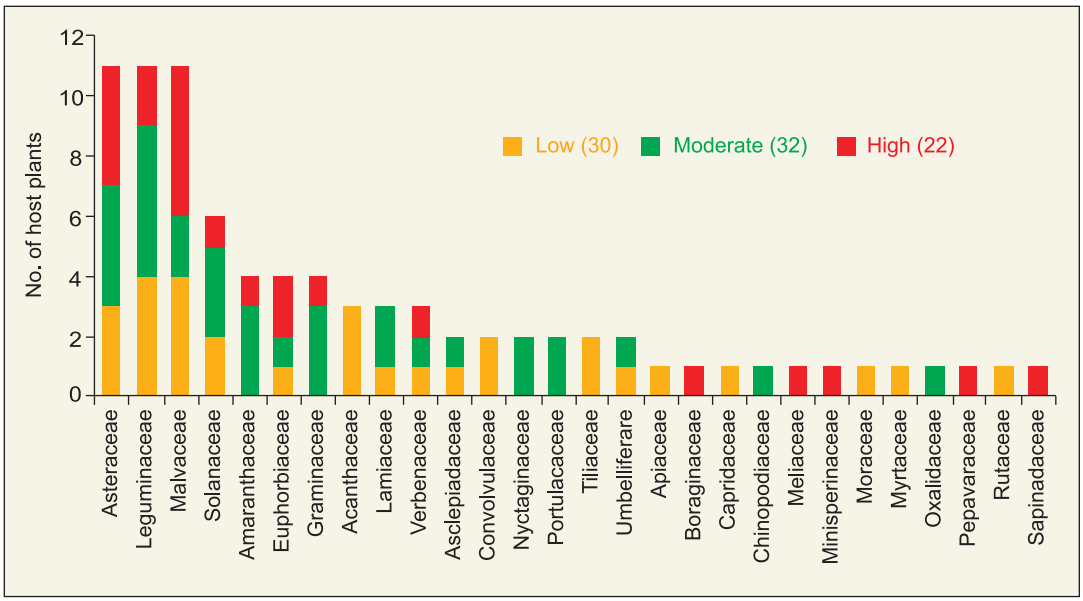

Fig. 10. Degree of dominance of *P. solenopsis* across families of host plants

Host plants of Malvaceae (*Abutilon theophrasti, Azanza lampas, Gossypium arboreum, Gossypium hirsutum, Malvastrum coramandelinum*) had higher vegetative dominance followed by Asteraceae (*Sonchus oleraceus, Tridax procumbens, Vicoa indica, Parthenium hysterophorus*), Euphorbiaceae (*Euphorbia hirta*, *Euphorbia geniculata*) and Leguminaceae (*Cajanus cajan*, *Cicer arientanum*). All the single host families with high vegetative dominance invariably supported *P. solenopsis* development during off season. Single host of Solanaceae (*Physalis minima*), Graminaceae (*Cynodon dactylon*), Verbanaceae (*Lantana camara*), Boraginaceae (*Trichodesma indicum*), Meliaceae (*Azadirachta indica*), Minisperinaceae (*Cocculus hirsutus*), Papaveraceae (*Argemone mexicana*), Sapinadaceae (*Cardiospermum helicacabum*) had also higher vegetative dominance. But only *Cardiospermum helicacabum* of Sapinadaceae had Grade 4 severity. Among the single plant species families *Cleome viscosa* of Capridaceae had a maximum severity of Grade 3 despite its low vegetative dominance. Ten out of 46 off season hosts had higher vegetative dominance (Fig. 11) and 8 of them were weeds. But for ornamental plants *viz*., *Hibiscus rosa-sinensis* and *Vicoa indica*, vegetable crops, *Hibiscus sabdariffa* and *Lycopercicon esculentum*, the field crop, cotton; and all other hosts during growing and off seasons were weeds.

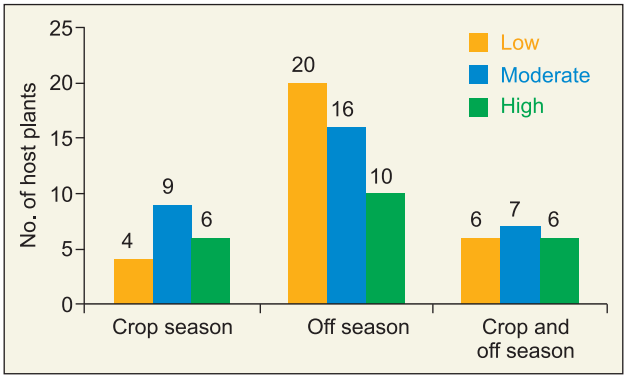

Fig. 11. Vegetative dominance of host plants of *P. solenopsis* across seasons

Out of nine G4 host plants with high vegetative dominance, three each *viz*., *Azanza lampas, Malvastrum coramandelinum* and *Gossypium hirsutum* (all Malvaceae), *Vicoa indica* (Asteraceae), *Euphorbia geniculata* (Euphorbiaceae) and *Physalis minima* (Solanaceae), and *Achyranthus aspara* (Amaranthaceae), *Parthenium hysterophorus* (Asteraceae) and *Cardiospermum helicacabum* (Sapinadaceae) (all weeds) were prevalent during growing season, off season and growing as well as off seasons, respectively (Fig. 12) . Salient highlight of *P. solenopsis* severity *vis a vis* vegetative dominance was that of preferential build up on Malvaceous, diverse and weed hosts in respect of growing, off season and growing and off seasons, respectively. It is also interesting to note that just a single off season weed host with

Family: Convolvuceae

Convolvulus arvensis

Family: Acanthaceae

Crossandra infundibuliformis

Family: Moraceae

Ficus religiosa

Family: Portulacaceae

Portulaca oleracea sativa

Family: Boraginaceae

Trichodesma indicum

Family: Myrtaceae

Psidium guajava

Family: Umbilliferare

Foeniculum vulgare

Centella asiatica

Family: Oxalidaceae

Oxalis corniculata

Family: Asclepiadceae

Calotropis gigantea

Hemidesmus indicus

Family: Pepavaraceae

Argemone mexicana

low dominance *viz., Convolvulus arvensis* had Grade 4 severity indicating the preference by *P. solenopsis* and the emphasis of selective host(s) to be managed. On the other hand, the number of off season hosts with medium dominance was the highest, highlighting the higher but general association of dominance of hosts and severity of *P. solenopsis*.

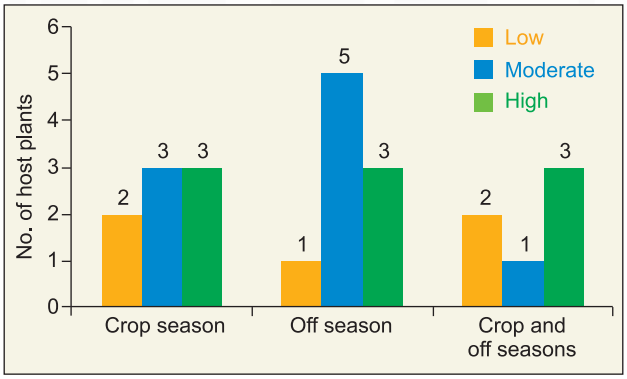

Fig. 12. Degree of dominance of G4 host plants of *P. solenopsis*

SPATIAL DISTRIBUTION OF HOST PLANTS *VIS A VIS* SEVERITY OF *P. SOLENOPSIS*

Species of plants present at field border (15) followed by those growing within fields as well as borders (12) served as hosts for *P. solenopsis*. Eight hosts each within fields and field cum roadside also supported *P. solenopsis* development. Nine hosts exclusive to road side, five common between field borders and roadside, and three across fields, borders and roadside harboured *P. solenopsis* (Fig.13). Extreme severity was higher among hosts growing within fields and borders, followed by those at field borders alone (Fig. 14).

Only one weed host *Phyllanthus niruri* (Euphorbiaceae) growing exclusively within field had Grade 4 severity of *P. solenopsis*. The

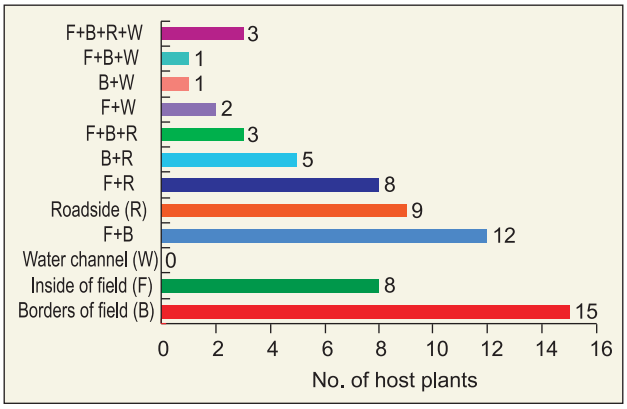

Fig. 13. Spatial distribution of host plants of *P. solenopsis*

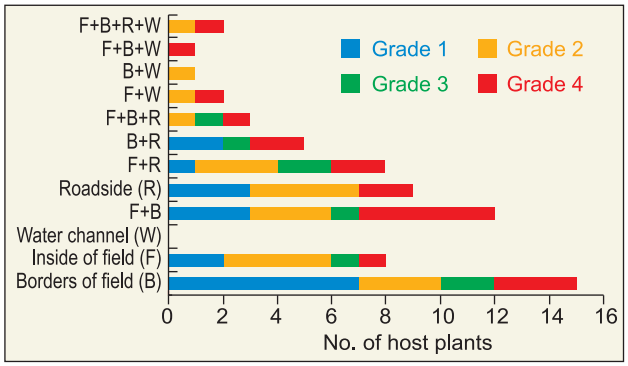

Fig. 14. Spatial severity of *P. solenopsis* on host plants

number of low severity (Grade 1) hosts was more at field borders over other locations.

P. solenopsis severity viewed in combination with vegetative dominance (Fig. 15) revealed higher severity among hosts with distribution across fields and its borders. Large number of hosts of field border and roadside with lower dominance supporting

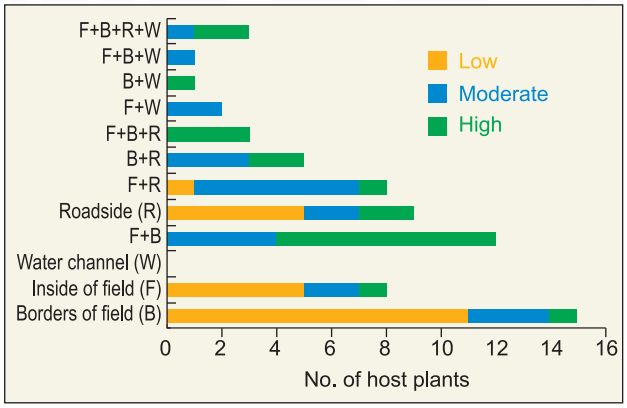

Fig. 15. Spatial dominance of host plants of *P. solenopsis*

Table 3: Spatial distribution, degree of vegetation and seasonality of G4 hosts of *P. solenopsis*

Location	Name of the host	Family	Vegetation	Seasonality
Borders of field (B)	*Acalypha indica*	Euphorbiaceae	Medium	Off season
	Convolvulus arvensis	Convolvulaceae	Low	Off season
	Hibiscus rosasinensis	Malvaceae	Low	Growing season
Inside of field (F)	*Phyllanthus niruri*	Euphorbiaceae	Low	Growing & off seasons
Roadside (R)	*Cardiospermum helicacabum*	Sapinadaceae	High	Growing & off seasons
	Tectona grandis	Verbenaceae	Medium	Growing season
B+R	*Azanza lampas*	Malvaceae	High	Growing season
	Abutilon indicum	Malvaceae	Medium	Off season
F+B	*Achyranthus aspara*	Amaranthaceae	High	Growing & off seasons
	Vicoa indica	Asteraceae	High	Off season
	Gossypium hirsutum	Malvaceae	High	Growing season
	Malvastrum coramandelinum	Malvaceae	High	Growing season
	Physalis minima	Solanaceae	High	Off season
F+R	*Boerhavia diffusa*	Nyctaginaceae	Medium	Off season
	Amaranthus viridis	Amaranthaceae	Medium	Growing & off seasons
F+W	*Taraxacum officinale*	Asteraceae	Medium	Off season
F+B+R	*Parthenium hysterophorus*	Asteraceae	High	Growing & off seasons
F+B+W	*Hibiscus sabdariffa*	Malvaceae	High	Growing season
F+B+R+W	*Euphorbia geniculata*	Euphorbiaceae	High	Off season
	Lycopercicon esculentum	Solanaceae	Medium	Off season

[1]: based on 36 individuals of females; [2]: based on eight individuals of males
**: Effective reproductive period was calculated based on the criteria of a minimum of ten crawlers produced by a female per day*

P. solenopsis development enlarges the scope of pest spread. The distribution and dominance of hosts of *P. solenopsis vis a vis* their seasonal occurrence with extreme severity confirmed the preferential build up on Malvaceous hosts within fields, border and roadside during growing season (Table 3). Diverse hosts of off season across varied locations of production system served as effective carry over hosts. However, sustenance of *P. solenopsis* was maintained by the highly dominant and continuously occurring hosts *viz*., *Parthenium hysterophorus* > *Achyranthus aspara* > *Cardiospermum helicacabum* > *Amaranthus viridis*. Selective management of these hosts along field borders, roadside and within field during growing + offseason could limit the temporal as well as spatial spread. Mealybug management campaigns targeting *P. hysterophorus* and other roadside hosts of *P. solenopsis* in Punjab during off season of 2008 has been instrumental in reducing the spread and severity of the pest in that region.

HOST RANGE *VIS A VIS* STRATEGY OF *P. SOLENOPSIS* MANAGEMENT

Wider host range of *P. solenopsis* in the cotton cropping system, its occurrence during growing and off seasons and severity facilitated continuous proliferation of the pest. Diversity of hosts suggested that *P. solenopsis* may attack many more plants with the passage of time, and weeds largely serve as temporal and spatial reservoirs. Field sanitation and weed removal with contained disposal during crop and off seasons play a significant role in preventing spread and severity of *P. solenopsis*. Cultural control of weed hosts with focus on moderate to high dominance hosts, and with severity Grade 3 and 4 along field borders, within fields and on roadside would not only suppress *P. solenopsis* but could eradicate the pest. Therefore, effective management of weeds and adopting crop rotation with non host crops in the crop production system would go a long way towards suppression of this pest.

BIOLOGY OF *P. SOLENOPSIS*

Knowledge on the biology of an insect at a given location with its environmental conditions on the crop of importance is necessary to understand the mode and degree of its population growth. Although the reports of occurrence and epidemics of *P. solenopsis* have been documented on cotton from several countries (Jhala and Bharpoda 2008b; Wang *et al*., 2009), details on biological parameters were not immediately explored due to the need for extensive standardization of the insect culture materials and methods. Since a study of the life history and pattern of biological activities are difficult under field conditions of cotton without interference of biotic and

abiotic factors, laboratory studies have become essential. While sprouted potatoes were used as a food source to maintain the mealybug colony for taxonomic and bioassay studies (Nagrare et al. 2009), this system was not realistic for an investigation of the mealybug's life history. Preliminary studies conducted in the laboratory using cotton leaves placed in Petri plates with intensive observations of reproductive and developmental stages of *P. solenopsis* formed the basis for the present study. Cotton leaves collected from the same position on the plant from only one cultivar provided similar food source for developing mealybugs, thus avoiding any variation in food quality. Since individual leaves could be placed in Petri plates, they were easily amenable to observations under the microscope.

Methodology

Studies on biology of *P. solenopsis* were carried out in the laboratory using the population collected from unsprayed cotton fields of *Gossypium hirsutum* L. (Malvales: Malvaceae) at the experimental station between August and October of 2009 with mean temperature and relative humidity of 23.3-30.2° C and 40.5-92.5% RH, respectively. Neonate crawlers that emerged from a field population were collected and constituted the study population. Since parthenogenetic reproduction of *P. solenopsis* was observed under field conditions, individual neonate crawlers emerging from females were used to start the biology study. A total of 250 crawlers drawn from different females but laid on the same day were individually transferred to separate glass Petri plates (15 X 2 cm) each containing a cotton leaf.

Description of stages

The female mealybug is wingless with a 3-4 mm long oval shaped body which is covered with white hydrophobic (water repellent) mealy wax. There are dark bare spots on the thorax and abdomen, which appear as dark longitudinal lines. The adult male is about 1 mm long, with a grey body and a single pair of transparent wings. Two filaments of white wax project from the end of its abdomen. The adult male has reduced mouthparts and causes no damage. Mature females lay eggs in waxy pouches called ovisacs. Each ovisac contains eggs, the majority of which are females. The eggs hatch after three to nine days into nymphs called 'crawlers', which are very mobile.

Life history parameters

The developmental period of crawlers of *P. solenopsis* was shorter and similar for first and third instars (2-6 days), and longer for the second instar (2-11 days).

Mean developmental periods of first, second and third instars were 3.9 ± 0.4, 5.1 ± 3.2 and 4.2 ± 0.6, respectively. Males had an additional instar and prepupal stage over 5-7 days of development with a mean of 5.5 ± 0.5 days. The mean total developmental period for crawlers with three instars, and four instars that developed into females and males, was 13.2 ± 1.8 and 18.7 ± 0.9, respectively. Females had a wider range of developmental periods than males. While the survival of first and third instars was the same (71.4%), the second instar had only 45.5% survival, and females survived (92.7%) better than males (83.3%). (Table 4). Females after the final moult took about 2-8 days for reproduction with a mean pre reproductive period of 5.7 ± 1.7 days. Reproduction by *P. solenopsis* was parthenogenetic with 96.5 and 3.5% of offspring produced as crawlers and eggs through ovoviviparity and oviparity, respectively. Under laboratory conditions the typical occurrence of an ovisac was

Table :4. Developmental period and survival of eggs and crawlers of *P. solenopsis*

Particulars	Developmental period of instars (days)				Total developmental period (days)		Incubation period for eggs (minutes)
	First	Second	Third	Fourth*	Male	Female	
Mean±SD	3.9±0.4	5.1±3.2	4.2±0.6	5.5 ±0.5	18.7±0.9	13.2±1.8	68.5±33.0
Range	2-6	2-11	2-6	5-7	17-20	9-16	35 - 120
Number of observations (n)	178	81	58	12	10	41	15
Survival (%)	71.4	45.5	71.4	-	83.3	92.7	100

*: Crawlers that developed into males had fourth instar, and survival value is not available due to the difficulty in separating sexes at third instar

missing although neonates or eggs were entangled in hyaline waxy thread-like structures. Mean fecundity was 334.4 ± 82 with a range of 128- 812 crawlers per female. The maximum incubation period of eggs was 120 min with a mean of 68.5 ± 33.0 min. The duration of reproduction was as short as 10 days to a maximum of 47 days with a mean of 30.2 ± 8.2 days. Offspring production by adult females was disjunctive with one to seven non-reproductive periods with a mean of 2.4 ± 0.6 days interspersed between the reproductive phase of the life cycle. More than 10 crawlers per day were produced by females for a minimum and maximum period of 6 and 30 days,, with a mean effective reproductive period of 17.2 ± 4.3 days, during which 97.3% of crawlers were produced. Mean longevity of adult females was 42.4 ± 5.7 days with a range of 36-51 days (Table 5). Adult females at the end of reproduction died the very next day or lived up to a maximum of 6 days. Males were winged, delicate and non-feeding. The proportion of males to the total population used in the

Table :5. Reproductive parameters[1] and longevity[2] of *P. solenopsis*

Particulars	Pre reproductive period	Reproductive period		Fecundity (number of crawlers per female)	Fecundity during effective reproduction* (%)	Mode of reproduction (%)		Non reproductive stop overs (numbers)	Longevity (days)	
		Actual	Effective*			Oviparity	Ovoviviparity		Males	Females
Mean±SD	5.7±1.7	30.2±8.2	17.2±4.3	334.4 ± 82	97.3	3.5	96.5	2.4±0.6	1.5±0.1	42.4 ±5.7
Range	2-8	10-47	6-30	128 - 812	82 - 99.7	0 - 8.3	92 - 100	1-7	1-2	36-51

[1]: based on 36 individuals of females; [2]: based on eight individuals of males

**: Effective reproductive period was calculated based on the criteria of a minimum of ten crawlers produced by a female per day*

study was 0.05, and they lived for a maximum of 2 days with a mean of 1.5 ± 0.1 days.

Longer developmental duration of males over females was due to an additional molting and prepupal processes. While the longer developmental period of 2nd instar of males along with high mobility could be the reason for their lower survival, it could not be separately observed for fourth instar due to the scarce population of males, together with the difficulty of observation of any sex related differences during early crawler stages. Akintola and Ande (2008) while reporting the first record of *P. solenopsis* on *H. rosa-sinensis* found progressively increasing developmental periods of 6, 8 and 10 days in respect of 1st, 2nd and 3rd instars, respectively. However *P. solenopsis* under laboratory conditions of rainfed cotton growing region revealed longer developmental period for 2nd instar over other two instars, indicating the influence of ecological zone with the associated weather conditions as well as host plants to exert influence on *P. solenopsis* development. The total developmental duration of a closely related species *Phenacoccus madeirensis* Green reared at constant temperatures of 25, 20 and 15^{0}C was reported to be 30, 46 and 66 days, respectively (Chong *et al.* 2003). Much shorter developmental periods of *P. solenopsis* together with the pattern of crawler production and wider range of fecundity by females observed in the present study under wider day to day temperature and humidity conditions indicated the acclimatization of *P. solenopsis* to tropical environment and its successful rapid spread across widely differing agro climatic zone of the Indian continent. Lower proportion and shorter life span of males denoted their insignificant role in reproduction, although under field conditions sexual reproduction also could be a possibility. Asexual reproduction in *P. solenopsis* confers demographic advantages when the host plant adaptations are high.

Description of all reproduction by *P. solenopsis* as sexual by Hodgson *et al*. (2008) is contrary to the observations of the present study. Upholding the reported results it evolves that *P. solenopsis* is variable in terms of behavioral and developmental patterns. Tanwar *et al*. (2007) described many species of mealybugs including *P. solenopsis*, and attributed the buildup of mealybugs to abiotic changes in the environment. The narrow genetic diversity of *P. solenopsis* population established across the country through molecular studies (ICAC recorder, 2008) only point out to the decisive role of ecological influences on the biology of *P. solenopsis*. It is to be mentioned that the studies that are underway to determine developmental rates at different constant temperatures in growth chambers would be able to assess the ability of *P. solenopsis* to multiply, survive and spread across regions among many host plants and the effect of environmental factors.

BIOLOGY *VIS A VIS* STRATEGY OF *P. SOLENOPSIS* MANAGEMENT

From the applied entomological perspective, it has been observed that the symptoms of mealybug infestation on the crop become obvious at times of maximum number of reproducing females found on the plants. Viewed in conjunction with the biology of *P. solenopsis* it is quite clear that the longevity of the adults exceeding the developmental period, expectedly the bigger size with increased waxy coating and the higher food requirement lead to visibility of the pest and symptoms, respectively on the crop. Therefore, with the initial notice of *P. solenopsis* infestation on few plants in a field or in some fields in an area, it is essential to monitor regularly for at least up to a fortnight to 20 days, coinciding with effective reproduction by females to make curative management decision using insecticidal sprays. Higher mortality of the crawlers, longer effective reproductive period and increased longevity of adult females deduced through the present study along with the expected natural mortality factors such as predation, parasitization and action of abiotic factors on crawlers over adults under natural field conditions suggest the focus of management interventions against reproducing adult females for preventing the multiplication and spread of the pest than on the crawlers. Therefore bioassay studies should use adult females over crawlers for determining an efficacious product for *P. solenopsis* management.

P. SOLENOPSIS – WEATHER ASSOCIATION

Preliminary analysis based on single year's data indicated significant influence of rainfall in reducing the severity of *P. solenopsis* but not the incidence. Rain water splashes and movement aid in dispersal of the mealybugs to shorter as well as longer distances, and spread of incidence is seen.

NATURAL BIO AGENTS OF MEALYBUGS

Parasitoids

Cotton plant parts infested by mealybugs *viz., P. solenopsis* and *M. hirsutus* were collected through fortnightly random surveys from cotton fields of Vidarbha region of Central India. Samples of mealybug species were transported to the laboratory using cloth bags. Third stage crawlers yet to form waxy coating were separated, and kept on healthy and unsprayed cotton leaves in glass Petri plates (15X2 cm). Change of cotton leaves and observations on survival of mealybugs were made on alternate days. Hardened puparia of parasitoids were separated and kept in glass vials till emergence and adult parasitoids were preserved in 70% alcohol. Species identity was established by Insect Identification Service Centre of Indian Agricultural Research Institute, New Delhi. A total of ten Hymenopterans belonging to five families were documented as parasitoids on mealybugs (Table 6).

Table 6: Diversity of Hymenopteran parasitoids of *P. solenopsis* and *M. hirsutus*

S.No.	Parasitoid name	Family	Host species
1	*Aenasius bambawalei* Hayat	Encyrtidae	*P. solenopsis*
2	*Aprostocetus bangaloricus* Narendran	Eulophidae	
3	*Promuscidea unfasciativentris* Girault	Aphelinidae	
4	*Encyrtus aurantii* (Geoffroy)	Encyrtidae	*P. solenopsis* and *M. hirsutus*
5	*Prochiloneurus pulchellus* Silvestri		
6	*Anagyrus dactylopii* (Howard),		
7	*Anagyrus mirzai* Agarwal and Alam		
8	*Homalotylus albiclavatus* (Agarwal)		
9	*Chartocerus kerrichi* (Agarwal)	Signiphoridae	*M. hirsutus*
10	*Pachyneuron leucopiscida* Mani	Pteromalidae	

Three species of parasitoids *viz., Aenasius bambawalei* Hayat (Encyrtidae), *Promuscidea unfasciativentris* Girault (Aphelinidae) and *Aprostocetus bangaloricus* Narendran (Eulophidae) were recorded on *P. solenopsis*. Five encyrtids *viz., Encyrtus aurantii* (Geoffroy), *Prochiloneurus pulchellus* Silvestri, *Anagyrus dactylopii* (Howard), *Anagyrus mirzai* Agarwal and Alam and *Homalotylus albiclavatus* (Agarwal) and one each of Aphelinidae *Promuscidea unfasciativentris* Girault), Signiphoridae (*Chartocerus kerrichi* (Agarwal), Pteromalidae (*Pachyneuron leucopiscida* Mani) and Eulophidae (*Aprostocetus bangaloricus* Narendran) were also documented as parasitoids of *M. hirsutus* during the current study.

Parasitoids of mealybugs

Puparia and *adults of Aenasius bambawalei*

P. unfasciativentris

P. pulchellus

E. aurantii

E. mirzai

C. kerrichi

A. dactylopii

H. albiclavatus

P. leucopiscida

Predators

Coccinellids (Coccinellidae: Coleoptera) *viz., Brumoides suturalais* (F.), *Cheilomenes sexmaculata* (F.) *Scymnus castaneus* Sicaid and *Cryptolaemus montrouzreri on P. solenopsis* and *Gitonides perspicax* Knab (Drosophilidae;Diptera) on *M. hirsutus* were found as predators.

Quantification of parasitisation of *P. solenopsis*

Weekly collections of both the mealybug species from unsprayed cotton fields

were brought to the laboratory during 2008 crop season. Mealybugs were cultured on cotton leaves for observation on parasitoid development. While reproducing healthy females were discarded, hardened mealybugs representing parasitoid puparia were kept in test tubes. Level of parasitisation was expressed as per cent of the ratio of the number parasitised to the total mealybugs used for observations. Parasitisation of *P. solenopsis* was noted almost at all periods of mealybug infestation. Seasonal mean parasitization of *P. solenopsis* by *A. bambawalei* and *P. unfasciativentris* together was estimated to be 21 per cent with a maximum of 48 per cent during August during 2008 – 09 cotton season (Fig. 16).

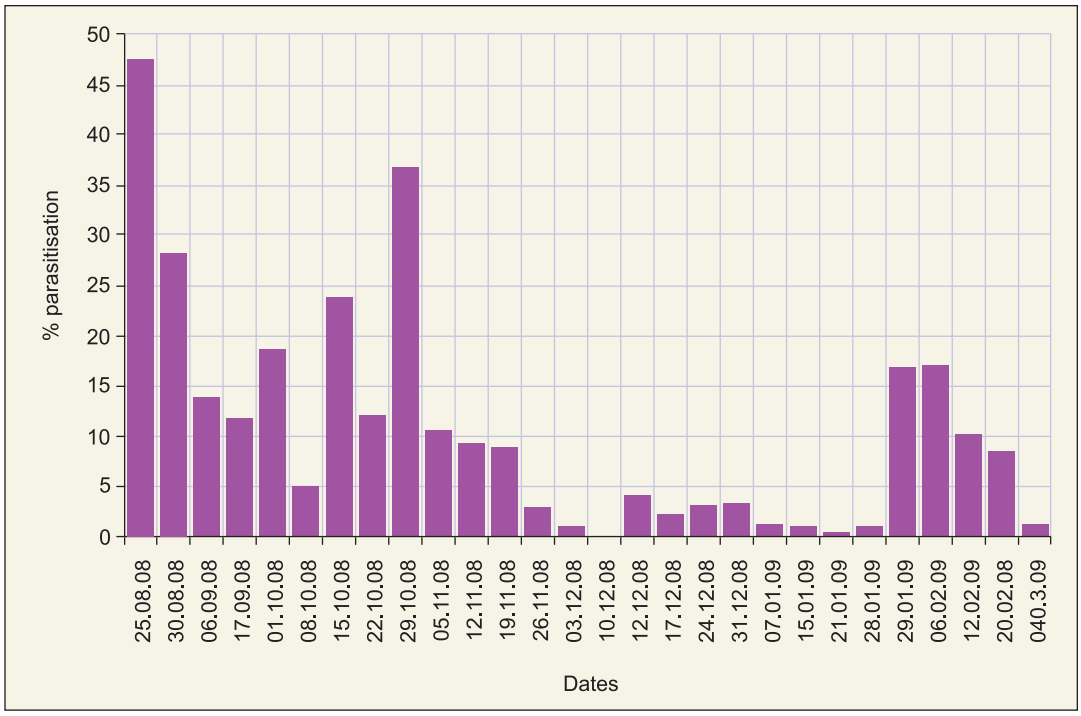

Fig. 16. Levels of combined parasitisation of *P. solenopsis* by *A. bambawalei* and *P. unfasciativentris*

Parasitisation levels of *P. solenopsis* measured from the point of spread of incidence and severity of an infested field location indicated the early higher parasitisation even at low infestation levels during September, followed by alternating high and low parasitisation levels during the period of increasing proportion of G4 plants. However, late season parasitisation was lower despite increasing infestation and G4 plants (Fig. 17). Correlative analysis between spread of incidence on cotton

and parasitoid occurrence was significantly negative (Table 7). Such a negative relation was due to the localized occurrence of *P. solenopsis* with mean severity not exceeding Grade 2 at any one period during the season. Overall low severity of *P. solenopsis* throughout the season was also responsible for the positive but non significant association of severity and parasitoid levels.

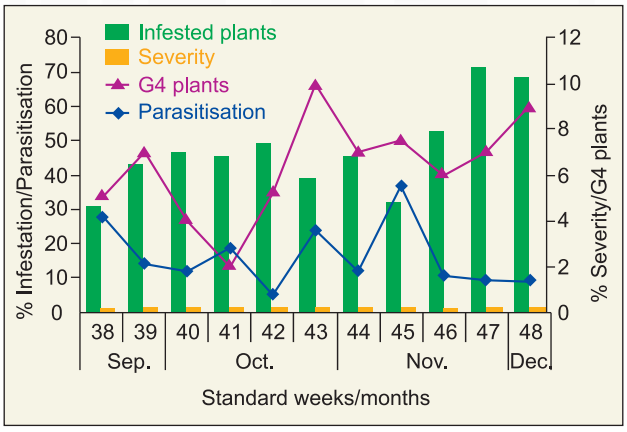

Fig. 17. Parasitisation of *P. solenopsis* in relation to its incidence and severity

Table 7: *P. solenopsis*-parasitoid relations on cotton

Particulars of mealybug	Mealybug-parasitoid relations (r values)
% infested plants	-0.75 **
% severity	0.14
% G4 plants	0.11

*** : significant at p ≤ 0.01*

P. solenopsis was parasitized by *A. bambawalei* and *P. unfasciativentris* on eight other host plants in addition to cotton during growing as well as off seasons (Table 8).

Table 8: Host plants with *P. solenopsis* - parasitoid association

S. No.	Local name	Botanical name	Family
1.	Gajar gavat	*Parthenium hysterophorus*	Asteraceae
2.	Ran shevanti	*Vicoa indica*	
3.	Mothi Doodhi	*Euphorbia geniculata*	Euphorbiaceae
4.	Ambadi	*Hibiscus sabdariffa*	Malvaceae
5.	Petari	*Abutilon indicum*	
6.	Malvastrum	*Malvastrum coramandelinum*	
7.	Nani Khapat	*Abutilon theophrasti*	
8.	Tomato	*Lycopersicon esculentum*	Solanaceae

View of field parasitisation of *P. solenopsis* (left) and *M. hirsutus (right)*

Closer view of parasitized mummies of *P. solenopsis* (left) and *M. hirsutus* (right)

Diverse groups of Hymenopterous parasitoids regulate the population of *P. solenopsis* effectively under field conditions of rainfed cotton. Considering the significant population suppression of mealybugs by native parasitoids, it is essential to preserve and encourage natural biological control. Strategies of mealybug management must place top priority on the cultural control and natural biological control provided by natural enemies. Need based curative measures using selective insecticides safer to parasitoids would go a long way in tackling mealybugs effectively.

CONCLUSION

Although reasons for mealybugs attaining pest status on cotton are still speculative on the grounds of wide spread cultivation of Bt transgenics and the resultant reduced insecticidal sprays, and overall changes in climate favouring their build up in the Northern cotton growing states, the immediate recognition of the basic tenets of the insects' spread potential, yield losses, host range and biology and natural regulation of population by environmental forces before its epidemics at Central zone could lead to formulation of management strategies exclusively based on non chemical methods. It was expected that numerous and diverse groups of host plants would facilitate rapid spatial spread of the mealybugs. In nature, wider host range of

P. solenopsis rather kept away the outbreaks on cotton in the production system. Since the occurrence of *P. solenopsis* was on large number of weed hosts over agriculturally important crop plants, cultural management practices of field sanitation in general, and weed removal with contained disposal during crop and off seasons in particular played a significant role in preventing spread of *P. solenopsis*. Studies on biology explained the appearance of symptoms on cotton crop in the field only when reproducing females were abundant on account of their longer longevity besides prolonged reproductive behaviour. Duration of adulthood and parthenogenesis by *P. solenopsis* females higher than the developmental duration also revealed the need to identify chemical insecticides effective against adults over crawlers. The control offered by these hymenopterans on *P. solenopsis and M. hirsutus* based on the abundance of adult emergence was of the order *A. bambawalei* > *P. unfasciativentris* > *A. bangaloricus*, and *E. aurantii* > *P. unfasciativentris* > *P. pulchellus* > *C. kerrichi*, respectively. Since parasitoids regulate the population of *P. solenopsis* and *M. hirsutus* effectively under field conditions, strategies of mealybug management placing priority for natural control coupled with cultural control before the curative measure of spray of insecticides would go a long way in tackling mealybugs in cotton fields.

ANNEXURE 1

Host records of *P. solenosis* in Central Indian Cotton Production System

S. No.	Family name (number of hosts)	Botanical name	Common names Marathi/English	Maximum grade	Seasonality		Dominance	Location[$]	Ant association*	Plant category
					Cotton season (G)	Off season (OS)				
1	**Asteraceae**	*Tagetus sp.* L.	Zendu /Marigold	2	G	OS	Medium	F,B	…	Ornamental
2	**(11)**	*Tridax procumbens* L.	Ekdandi/ Coat buttons	3	G	OS	High	F,B,R	2	Weed
3		*Parthenium hysterophorus* L.	Gajar gavat/ Carrot grass	4	G	OS	High	F,B,R	2	Weed
4		*Bidens pilosa* L.	Chikta/ Spanish needle	1	G		Medium	…	…	Weed
5		*Xanthium strumarium* L.	Gokharu/ Bourr weed	2	G		Medium	F,B	2	Weed
6		*Sonchus oleraceus* L.	Pachar/ Sow thistle	2	G		High	…	…	Weed
7		*Lactuca runcinata* L.	Pathari / Cabbage lettuce	4	G		Low	…	…	Weed
8		*Gaillardia pulchella* Fouger	Gaillardia / Firewheel	2		OS	Low	R	…	Weed
9		*Baccharoides anthelmintica* L.	Kadu Jira/ Iron weed	2		OS	Low	F		Weed
10		*Vicoa indica* (L.) DC.	Ran shevanti/ Sonkadi	4		OS	High	F,B	2	Ornamental
11		*Taraxacum officinale* Wigg.	Pachar like / Dandelion	4		OS	Medium	F,W	…	Weed
12	**Leguminaceae (11)**	*Clitoria ternatea* L.	Shankupushpi / Butterfly pea	1	G	OS	Medium	B,R		Weed
13		*Crotalaria verrucosa* L.	Ghungroo/ Dog pea	1	G	OS	Medium	B,R		Weed
14		*Desmodium diffusum*	Shewari/ Begger weed	1	G		Medium	…	…	Weed
15		*Lablab purpureus* Isweet	Bean/ Field Bean	1	G		Medium	B	…	Vegetable
16		*Cassia tora* L.	Tarota/ Coffee weed	2	G		Low	R	…	Weed
17		*Butea monosperma* Roxb.	Palas/ Flame of forest	1		OS	Low	B	…	Plantation
18		*Rhychosia minima* DC.	Jangli mug / Nani-kamalvel	1		OS	Low	F	…	Weed
19		*Cajanus cajan* (L.) Mill.	Toor/ Pigeon pea	2		OS	High	B,W	2	Field Crop
20		*Leucaena leucocephala* Benth.	Subabul/ Horse tamarind	2		OS	Low	B	…	Plantation
21		*Cicer arietinum* L.	Chana/ Chick pea	2		OS	High	F	…	Field Crop
22		*Psoralea corylifolia* L.	Bawchi Babchil/ Fountain bush	2		OS	Medium	F,R	…	Weed
23	**Malvaceae**	*Hibiscus rosasinensis* L.	Jaswand/shoe flower	4	G	OS	Low	B	2	Orna
24	**(11)**	*Abutilon theophrasti* Medic.	Nani Khapat/ Indian mallow	2	G		High	B,R	1,3	Weed
25		*Gossypium arboretum* L.	Kapas/ Cotton	3	G		High	F,B	2,3	Field Crop
26		*Azanza lampas* (Cav.) Alef.	Jangli-bhendi	4	G		High	B,R	2	Weed

S. No.	Family name (number of hosts)	Botanical name	Common names Marathi/English	Maxi-mum grade	Seasonality		Dominance	Loca-tion[$]	Ant associ-ation*	Plant category
					Cotton season (G)	Off season (OS)				
27		*Gossypium hirsutum* L.	Cotton/ Upland cotton	4	G		High	F,B	2,3	Field Crop
28		*Malvastrum coramandelinum* (L.) Garcke	Malvastrum/three lobe false mallow	4	G		High	F,B	2	Weed
29		*Hibiscus sabdariffa* L.	Ambadi/Roselle	4	G		Medium	F,B,W	2	Vegetable
30		*Abelmoschus esculentus* (L.) Moench	Bhendi,/ Okra,	2		OS	Low	B	2	Vegetable
31		*Hibiscus panduraeformis* Burm	Jangli Bhendi/ Wild Lady's Finger	2		OS	Low	R		Weed
32		*Abelmoschus manihot* (L.) Medikus	Ran bhendi/ Sweet Hibiscus	3		OS	Low	B	....	Weed
33		*Abutilon indicum* (L.) Sweet.	Petari/ Indian mallow	4		OS	Medium	B,R	1,2,3	Weed
34	**Solanaceae (6)**	*Solanum melongena* L.	Baigan/ Brinjal	2		OS	Medium	F,B	2	Vegetable
35		*Capsicum annuum* L.	Mirchi/ chilli	2		OS	Low	B	...	Vegetable
36		*Solanum nigrum* L.	Kamooni/ Black night shade	2		OS	Low	F	...	Weed
37		*Solanum xanthocarpum*	Ran Wangi/ Yellow berried nightshade	2		OS	Medium	R		Weed
38		*Physalis minima* L.	Kapalfodi/ Ground cherry	4		OS	High	F,B	2	Weed
39		*Lycopercicon esculentum* Mill.	Tomato/ Love apple	4		OS	Medium	F,B,R,W	1	Vegetable
40	**Amaranthaceae**	*Alternanthera triandra* Lam.	Reshimkata	3	G	OS	Medium	F	...	Weed
41	**(4)**	*Amaranthus viridis* L.	Chawali/ Wild Amaranthus	4	G	OS	Medium	F,R	2	Weed
42		*Achyranthus aspara* L.	Agarha/ Prickly Chaff	4	G	OS	High	F,B	...	Weed
43		*Celosia argentia* L.	Kombada/ Wild Cock's comb	1		OS	Medium	...	...	Weed
44	**Euphorbiaceae**	*Euphorbia hirta* L.	Med. Doodhi/ Garden spurg	3	G	OS	High	B	...	Weed
45	**(4)**	*Phyllanthus niruri* L.	Hazardani/ Stonebreaker	4	G	OS	Low	F	...	Weed
46		*Euphorbia geniculata* L.	Mothi Doodhi/ Spurg	4		OS	High	F,B,R,W	2	Weed
47		*Acalypha indica* L.	Deepmal/ Copper leaf	4		OS	Medium	B	...	Weed
48	**Graminaceae (4)**	*Eragrostis tef* (Zucc.) Trotter	Lahan Chimanchara/ Tef grass	1	G		Medium	...	...	Weed
49		*Dinebra sp.*	Shimpi	3	G		Medium	F,R	...	Weed
50		*Panicum javanicum* Poir.	Kena like (Git)/ Blue panic	1		OS	Medium	...	...	Weed
51		*Cynodon dactylon* (L.)Pers	Hariyali/ Couch grass	1		OS	High	F,R	...	Weed

S. No.	Family name (number of hosts)	Botanical name	Common names Marathi/English	Maxi-mum grade	Seasonality		Dominance	Loca-tion[$]	Ant associ-ation*	Plant category
					Cotton season (G)	Off season (OS)				
52	**Acanthaceae (3)**	*Crossandra infundibuliformis* L.	Aboli / Fire craker plant	1		OS	Low	B	...	Ornamental
53		*Asteracantha longifolia* Nees	Kateri bid/ Water spiny ball	1		OS	Low	R		Weed
54		*Rungia repens* Nees.	Kharmor/Purple Crosandra	3		OS	Low	...	...	Weed
55	**Lamiaceae (3)**	*Ocimum basilicum* L.	Ran tulsi/ Sweet basil	2	G		Low	F,R		Weed
56		*Leucas urticaefolia* Br.	Dronpushpi/ White dead nettle	1		OS	Medium	F,B	2	Weed
57		*Ocimum sanctum* L.	Tulsi/ Indian Bassil	2		OS	Medium	F,R	...	Medicinal Plant
58	**Verbenaceae**	*Duranta repens* L.	Pivali Mendi/ Golden duranta	1	G	OS	Low	...	...	Weed
59	**(3)**	*Tectona grandis* L. F.	Teak (Sagwan)/ Indian oak	4	G		Medium	R	3	Weed
60		*Lantana camara* L.	Ghaneri/ Surinum tea plant	2		OS	High	F,B,R,W	...	Weed
61	**Asclepiadaceae (2)**	*Hemidesmus indicus* (L.) R.Br.	Khobarvel / Indian sarasaparilla	2	G	OS	Medium	F,W	2	Weed
62		*Calotropis gigantea* R.Br.	Rui/ Gigantic Swallow Wart	1		OS	Low	B	2	Weed
63	**Convolvulaceae**	*Ipomea carnea* Jacq.	Beshrum/ Blue morning glory	1		OS	Low	B	1	Weed
64	**(2)**	*Convolvulus arvensis* L.	Chandvel / Field bind weed	4		OS	Low	B	...	Weed
65	**Nyctaginaceae (2)**	*Boerhavia repens* Chois.	Punarnava/ Spreading hog weed	3		OS	Medium	F,R		Weed
66		*Boerhavia diffusa* Chois.	Khaparfuti/ spider ling	4		OS	Medium	F,R	...	Weed
67	**Portulacaceae (2)**	*Portulaca quadrifida* L.	Chival/ Common Indian purselane	4	G		Medium	...	...	Weed
68		*Portulaca oleracea* sativa L.	Ghol/ Common Indian purselane	3		OS	Medium	...	...	Weed
69	**Tiliaceae (2)**	*Corchorus trilocularis* L.	Jangli Jute/ Wild Jute	1	G	OS	Low	...	...	Weed
70		*Triumfetta rhomboidea* Jacq.	Gokharu like/ Burr bush	1	G	OS	Low	R		Weed
71	**Umbelliferae (2)**	*Foeniculum vulgare* Miller	Saunf/ Funnel	1		OS	Medium	B	...	Spice
72		*Centella asiatica* (L.) Urt.	Jangli kobi/ Penny wort	4	G		Low	...	...	Weed
73	**Apiaceae (1)**	*Trachyspermum amoni* (L.) Sprague	Ajavan/ Bishop's weed	1		OS	Low	.....	...	Spice
74	**Boraginaceae (1)**	*Trichodesma indicum* R.Br.	Chottakulpa / Indian borage	1		OS	High	F,B	...	Weed
75	**Capridaceae (1)**	*Cleome viscosa* L.	Hurhur/ Wild mustard	3		OS	Low	...	...	Weed

S. No.	Family name (number of hosts)	Botanical name	Common names Marathi/English	Maxi-mum grade	Seasonality		Dominance	Loca-tion*	Ant associ-ation*	Plant category
					Cotton season (G)	Off season (OS)				
76	**Chinopodiaceae (1)**	*Beta vulgaris var bengalensis* L.	Palak/ Spinach	1	G	OS	Medium	F		Vegetable
77	**Meliaceae (1)**	*Azadirachta indica* A. Juss.	Kadu Neem/ Margosa	1		OS	High	R		Plantation
78	**Minisperinaceae (1)**	*Cocculus hirsutus* L.	Vasanvel	2		OS	High	F,B,R	...	Weed
79	**Moraceae (1)**	*Ficus religiosa* L.	Peepal/ Bodhi tree	1		OS	Low	....	...	Plantation
80	**Myrtaceae (1)**	*Psidium guajava* L.	Guava /Peru	2		OS	Low	F	1	Fruit
81	**Oxalidaceae (1)**	*Oxalis corniculata* L.	Amrool/ Indian sorrel	1		OS	Medium	...	...	Weed
82	**Papaveraceae (1)**	*Argemone mexicana* L.	Satyanashi / Mexican Poppy	1	G	OS	High	F,B	3	Weed
83	**Rutaceae (1)**	*Murrya koenigii* Spreng	Kadhi patta/ Curry leaf	1	G	OS	Low	B		Medicinal Plant
84	**Sapinadaceae (1)**	*Cardiospermum helicacabum* L.	Fataka/ balloon vine	4	G	OS	High	R	...	Weed

s: ***Borders of field (B); Inside of field (F); Water channel (W); Roadside (R).***
**** : 1: Componotus compressus*** Fabricius***; 2: Monomorium indicum*** Forel***; 3: Yet to be identified***

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