POPULATION DYNAMICS AND MANAGEMENT OF ERYTHRINA GALL WASP *Quardrastichus erythrinae* Kim.

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DECLARATION

I hereby declare that this thesis entitled "**Population dynamics and management of Erythrina gall wasp *Quadrastichus erythrinae* Kim.**" is a bonafide record of research work done by me during the course of research and that this thesis has not previously formed the basis for the award of any degree, diploma, associateship, fellowship or other similar title, of any other university or society.

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Certified that this thesis entitled "**Population dynamics and management of Erythrina gall wasp *Quardrastichus erythrinae* Kim.**" is a record of research work done independently by Ms. Beena, M.P. (2005-11-104) under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associateship to her.

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DEDICATED TO
MY FATHER

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"Om Bhur Bhuva Suvah
Tat Savithur Varenyam
Bhargo Devasya Dheemahi
Dhiyo Yonah Prachodayat"

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INTRODUCTION

1. INTRODUCTION

Galls are formed from unusual vegetative growth produced by a plant under the influence of an insect, mite, bacteria, fungus or nematode. It involves the intimate association of the plant host and the gall maker. Most plant galls are caused by the feeding or egg laying activity of insects and mites.

The three major groups of insects that cause galls are aphids and their relatives, gall midges and gall wasps (Tom and Don, 1990). Galls are natural plant products. Either mechanical damage or salivary secretions introduced by immature insects and mites initiate abnormal production of normal plant growth hormones. These plant hormones cause localized plant growth that can result in increases in cell size and/or in the number of cells. The outcome is an abnormal plant structure called a gall. Gall formation usually occurs during times of fast growth of new leaves, shoots, flowers, etc. The insect or mite develops inside the gall and the gall continues to grow as the insect/mite feeds and matures. Mature plant tissues are usually unaffected by gall-inducing organisms as they are insensitive to various gall-making stimuli. Consequently, most galls start in late spring and early summer when adult insects become active and lay eggs (Cranshaw, 2006).

Galls are growing plant parts and require nutrients just like other plant parts. It is possible that galls "steal" vital energy and adversely affect plant growth and it is more likely a problem in young plants. In most cases galls are not abundant enough to harm the plant. However, there are exceptions and galls may inhibit branch formation or distort foliage and flowers. Most gall-maker populations fluctuate from season to season. The occurrence of many gall makers in one year usually is followed by few in the next (Cranshaw, 2006).

One common group of gall makers are the gall wasps. Most gall wasps belong to the family Cynipidae, but a few sawflies and chalcid wasps also cause galls. Gall wasps are common on oaks, roses and related plants. The galls that they form may be located on any part of the plant, in diverse forms and shapes and can become common enough to make the plant's appearance unattractive. Despite the visual impact that heavy gall infestations can cause, the relationship between the plant host and the gall maker is so nicely balanced that infested plants are rarely killed by the gall maker (Tom and Don, 1990). Galls may be formed on roots, stems, fine branches, leaves, buds or flowering parts. It was originally believed that pricking of the plant tissue by gall wasp's ovipositor, or perhaps irritation caused by lubricating secretions produced by female gall wasp during oviposition, induced gall formation (Ananthakrishnan, 1986).

Erythrina or coral tree is interplanted as a shade tree in coffee and cocoa plantations and as a trellis plant for betel nut (*Piper betel*), black pepper, vanilla, and yam. The tree is cultivated throughout the tropics, particularly as an ornamental tree and as a shade and soil improvement tree. The coral tree gets its name from the bright red colour of the flowers. The bright red flowers add beautiful highlights to any landscape. The trees have compound leaves that are semi-deciduous, and these 6- to 8-inch-long leaves are composed of three shallow-lobed leaflets. Introduced pests have always been causing a great havoc to our native plants. One such introduced pest is the Erythrina Gall Wasp (EGW), *Quadrastichus erythrinae* Kim (Hymenoptera: Eulophidae). The EGW was first recorded damaging coral trees, in southern Taiwan in 2003 (Yang et al., 2004). In India the pest was reported by Faizal et al. (2006) from Kerala. Females typically have a special ovipositor for inserting eggs into hosts. The pest spread rapidly to the entire pepper growing tracts in Kerala where Erythrina is cultivated as trellises for pepper vines. Gall infested trellises either fall down with vines or die, either way affecting the pepper plants.

Considering the importance of the pest, the study entitled "Population dynamics and management of Erythrina gall wasp *Quadrastichus erythrinae* Kim" was formulated with the following objectives:

1. To make a detailed study of population dynamics.
2. To observe the activity and behavior.
3. To study histology of gall development.
4. To identify suitable chemical, biorational and plant based insecticides for management.
5. To assess the residues of insecticides in pepper due to drift from pesticide application.

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

Wasps of the family Eulophidae are parasitoids on a variety of arthropods with a few phytophagous species. Most of the species of the genus *Quadrastichus* are parasitoids (Yang et al., 2004) and *Q. erythrinae* is the only phytophagous and gall producing species reported from this genus (Faizal et al., 2006). The literature pertaining to the different aspects of EGW is less and they are presented.

2.1 OCCURRENCE OF *Q.ERYTHRINAE*

Campbell (2005) first identified the erythrina gall wasp in 2004 while examining specimens collected from Singapore, Mauritius and Reunion Islands. Hue et al. (2005) first collected samples of gall-damaged leaves and stems of the coral tree *Erythrina variegata* L., from Manoa, Oahu, on April 19, 2005. The galls were induced by the larvae of the tiny wasp which was identified as the erythrina gall wasp *Quadrastichus erythrinae* Kim (Eulophidae: Hymenoptera) (Kim et al., 2004)

2.2 HOSTS OF ERYTHRINA GALL WASP

The Erythrina gall wasp was first recorded damaging coral trees *Erythrina* spp. (Fabaceae), in southern Taiwan in 2003. Since then, it rapidly spread throughout the island on various species of *Erythrina* (Yang et al., 2004). The Erythrina gall wasp infests approximately 110 species of Erythrina around the world. Various species of Erythrina are used as ornamentals, 'living fences', and nitrogen-fixing components of agro forestry systems (Kim et al., 2004).

Erythrina species are also known as coral trees and have a variety of functions in different locations. In Taiwan, they are highly associated with farming and fishing activities. As indicated by its Latin name "erythros" meaning red, its obvious red flowers have been used as a sign of the arrival of spring and as a working calendar by tribal people. Specifically, the blooming of its showy red flowers signals the coastal people to begin their ceremonies for catching flying fish and the Puyama people to plant their sweet potatoes (Yang et al ., 2004).

E. variegata, with its bright red flowers, is also known as tigers claw, Indian coral tree, and wiliwili-haole. It is a common landscape tree in Hawaii. A tall, columnar form of *E. variegata*, "Tropic Coral," known locally as "tall erythrina" or "tall wiliwili," is used as a windbreak for soil and water conservation and for planting around farmsteads. The erythrina gall wasp infests the coral trees, *E. variegata*, *E. crista-galli*, and the native *E. sandwicensis* Degener (Rotar et al., 1986; Hue et al., 2006).

Yang et al. (2004) reported five species and a subspecies of coral trees as suitable hosts of Erythrina gall wasp viz. *Erythrina variegate* L., *Erythrina variegate* var. *orientalis* (L.) Merr., *Erythrina corallodendron* L., *Erythrina cristagalli* L., *Erythrina abyssinica* Lam., and *Erythrina berteroana* Urban.

Fakuda (2005) noticed that the older, tougher leaves on wiliwili appear to be less susceptible to the wasp than newer growth and that the endemic tree might be more resistant.

Faizal et al. (2006) reported *Erythrina stricta* Roxb. as the host of *Q. erythrinae* which is a quick-growing species with showy red flowers and is grown as a standard for trailing black pepper (*Piper nigrum* L.) and vanilla (*Vanilla planifolia* Andr.) throughout south India.

2.3 DISTRIBUTION OF ERYTHRINA GALL WASP

Hue et al. (2005) reported that erythrina gall wasp was described in 2004 as a new species by Kim et al. (2004) from the specimens collected from Singapore, Mauritius, and Reunion.

Faizal et al. (2006) reported severe incidence of *Q. erythrinae* on *E.stricta* in Thiruvananthapuram district, Kerala since April, 2005. Basabaraj (2006) observed infested trees in Pune, Satara, Sangli and Kollhapur districts of Maharashtra and Belgaum and Dharwad districts of Karnataka. He also observed that the severity was so acute that galled plants did not flower at all and only the skeleton of plants with galled terminal ends of the shoot system that appeared dark black .Even after heavy showers the infested plants did not produce new foliage.

2.4 NATURE OF DAMAGE AND SYMPTOMS OF ATTACK

Yang et al. (2004) reported that severe gall wasp infestation caused defoliation and death of trees. They also explained that galls were seen on the leaves, petioles, young shoots, and stems. Obvious swelling could be seen on infested tissue parts, and severe infestations caused curling of young shoots, defoliation, and death of the trees.

Valerie (2005) reported that the wasp laid eggs in the leaf and stem tissues of wiliwili forming tumors that make the trees appear as if they have smallpox. All types of wiliwili, from the elegant native species to the introduced varieties,were reported to be affected.

Hue et al. (2006) and James and Paul(2006) reported that like other gall-forming eulophid wasps, the EGW inserted its eggs into young leaf and stem tissues. The wasp larvae developed within plant tissue, and induced the formation of galls in leaflets and petioles. As the infestation progressed, leaves curled and appeared deformed while petioles and shoots became swollen. After feeding was completed, larvae pupated within the leaf and stem tissues. The adult wasps emerged after cutting exit holes. Heavily galled leaves and stems resulted in the loss of growth and vigour. Trees with large population of wasps within the leaves and stem had reduced leaf growth, and the plant declined in health

Faizal et al. (2006) reported that the female wasp thrust eggs into tender tissues of shoots using the exerted ovipositor and the apodous, creamy white larvae developed individually in chambers formed inside the meristematic tissue. The proliferation of tissues in the attacked portion resulted in gall formation. Galls were formed on the entire developing stem, petiole and leaf lamina with characteristic enlargement and malformation. The thickness of galled petioles was 3.1 times more than that of normal. In the case of tender stems, infestation resulted in enhancement of mean thickness. Multiple galls with layers of larval chambers were formed in the affected portion. Infested leaves failed to attain the normal size and shriveled with thick galls on them. Petioles and tender stems enlarge in thickness and presented a curly appearance with knot-like galls on them. Severely infested branches appeared stunted and bushy. Galled leaves and tender branches finally dried up. As the newly emerged leaves were converted into galls, there was severe reduction in the number and size of leaves, besides complete cessation of growth. Such trees presented a scrawny appearance with malformed and crinkled shoot.

Schmaedick et al. (2006) reported that the adult female laid eggs inside young leaf and stem tissues. As the larvae fed and developed, they caused abnormal growth of plant tissues including small nodules on the leaf surface and uneven swelling and curling of leaf petioles and terminal stems followed by defoliation, stunting and even tree death.

2.5 BIOLOGY

2.5.1 Description of Adults

Yang et al. (2004) reported that erythrina gall wasp showed dimorphism in body colour. The female is yellowish brown, the male is white, and both have dark brown markings on the wings. This wasp possessed one dorsal seta, antennae with all funicular segments longer than wide, and gaster longer than the head plus mesosoma, but it was distinct from other species of the genus due to the presence of a long hypopygium. Kim Delvare and La Salle(2004)described the female and male adults and the details are given below.

2.5.1.1 Female

Female was yellowish brown in colour and the length ranged from 1.45 to 1.60 mm. Head was yellow, and the posterior side of gena was brown. Antenna was pale brown except scape which was posteriorly pale. Pronotum was dark brown. The mid lobe of mesoscutum had a "V" shaped or inverted triangular dark brown area from anterior margin and the remainder yellow. Scapula was yellow. Scutellum, axilla and dorsellum were brown to light brown. Propodeum was dark brown and gaster brown. Fore and hind coxae were brown and mid coxa almost pale. Femora was mostly brown to light brown. Specimens from Mauritius were generally darker than those from Singapore. The non protruding ovipositor sheath was short in dorsal view.

2.5.1.2 Male

Length of the male ranged from1.00 to 1.15 mm. Colouration of the male was white to pale yellow as opposed to yellow in female. Head and antenna were pale coloured. Pronotum was dark brown (but in lateral view, only upper half was dark brown; lower half yellow to white). Scutellum and dorsellum were pale brown axilla pale and propodeum dark brown. Gaster in anterior half was pale and remainder dark brown. All legs were pale coloured. Antenna had 4 funicular segments, without the whorl of setae .

2.5.2 Life Cycle

Studies conducted by the Hawaii Department of Agriculture (HDOA) indicated that life cycle of *Q.ertythrinae* was about 20 days. An one-day old female wasp contained about 60 mature eggs in its ovaries. The adult female wasp exhibited a preference for depositing eggs in very young terminal leaves and stems, but not in mature leaves. Adult wasps survived less than 3 days (males- 2.5 days, females - 2.9 days) without food while those provided with honey lived longer (males - 10.3 days, females - 6.1 days). The male: female ratio of emerging wasps from infested plants in the laboratory was 7:1 (ISSG, 2006 ; Hue et al., 2006). An examination under a scanning electronic microscope found that one female, on an average, carried 322 ± 98 eggs (Yang et al., 2004).

Faizal et al, (2006) reported that from a single abscised infested leaf, up to 271 wasps emerged. Similarly, a five centimeter long piece of galled petiole and tender stem produced up to 51 and 64 wasps respectively. Sex ratio of wasps emerging from galls was highly skewed towards males, with 2.7males emerged for each female.

2.6 CHEMICAL METHODS OF MANAGEMENT

Yang et al. (2004) reported that systemic insecticides were the effective agent to eliminate the developing insects in leaf galls. They also suggested the application of systemic insecticides, proper pruning and elimination of infested twigs and leaves for better control.

Faizal et al. (2006) reported that pruning failed to contain the damage. However, bark injection of the systemic insecticide imidacloprid had some effect in protecting new growth. Preliminary trials conducted with systemic insecticides suggested that an insecticide containing the active ingredient, imidacloprid helped to reduce damage to erythrina caused by the gall wasp (Hue et al., 2006). Schmaedick et al. (2006) reported that pruning was not found successful, but systemic insecticide appeared to be partly effective in protecting highly valued individual trees in Hawaii.

MATERIALS AND METHODS

3. MATERIALS AND METHODS

A series of laboratory and field experiments were done in the Department of Entomology and Instructional Farm, College of Agriculture, Vellayani in order to make an assessment of the population dynamics of Erythrina gall wasp, extent of damage caused by it and to identify suitable synthetic and plant based insecticides for the control of erythrina gall wasp

3.1 POPULATION DYNAMICS OF ERYTHRINA GALL WASP

3.1.1 Assessment of Pest Population

Six trees of *Erythrina stricta* moderately infested by EGW were identified for the study in the Instructional Farm, Vellayani. Six infested trifoliate leaves were collected from the trees at random every Tuesday consecutively for 78 weeks, commencing from the first week of January 2006. The samples were brought to the laboratory and the leaflets viz., left lateral (LL), terminal leaflet (TL), right lateral (RL) and the petioles were detached (Plate 1a). The weight of each leaflet and petioles and the number of galls on the samples were recorded. Depending on the degree of gall formation, the petioles were scored as detailed below (Plate 1b).

0-Petioles straight with no galls
1- Petioles curved with one to six galls
3- Petioles curved and thickened
5- Petioles curved and stunted
7-Petioles stunted and twisted
9- Petiole stunted and ball like

The mean intensity score (MIS) was worked out using the formula

$$\frac{\text{No: of samples in each respective grades X the number of respective grade}}{\text{Total No: of samples}}$$

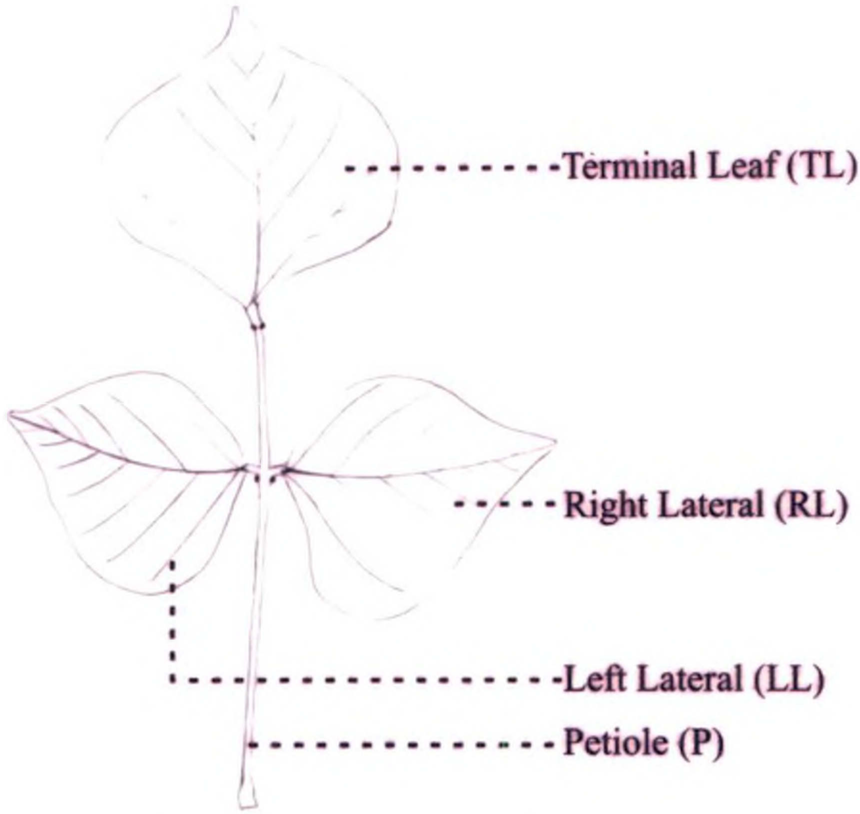


Plate 1a. Trifoliate leaf of *Erythrina stricta* showing sub samples for the study of population dynamics

Plate 1b. Degree of galling by *Quadrastichus erythrinae* on petioles of *E.stricta*

Each leaflet and the petioles were then kept in separate polypropylene covers (Plate 2) and the emerging adult wasps were anesthetized, sexed, counted and removed daily. The males and the females were identified based on the size and colour.

3.1.2 Influence of Weather Parameters on Pest Emergence

The data on various weather parameters *viz.* maximum and minimum temperature, rainfall and relative humidity during the period of observation were collected from the Department of Agro-metereology, NARP (SR), College of Agriculture, Vellayani and the population of EGW during 78 weeks (January 2006 – June 2007) was correlated with the weather parameters during the corresponding periods. Correlations were also worked out with the weather parameters that prevailed during one, two, three and four weeks prior to sampling.

3.1.3 Correlation Between Population of EGW and the Weight and Number of Galls Made by the Insect

Correlation was worked out on the population of EGW during the 78 weeks and corresponding observations on number of galls and weight of the respective samples.

3.2 INVESTIGATIONS ON THE TRENDS OF FOLIAGE PRODUCTION AND INFESTATION

To study the trend of foliage production, galling and defoliation due to infestation by *Q.erythrinae*, three trees propagated from the same clone in the B block of the Instructional farm,Vellayani was selected. The temporal pattern of foliage production, gall inducement, drying and abscission of galled parts and

Plate 2. Perforated polypropylene covers used to monitor emergence of EGW from infested plant parts

complete cessation of growth was assessed by visual estimation. Each stage was documented and illustrated through line art drawings.

3.3 NATURE OF DAMAGE

Nature of damage in various plant parts due to galling by EGW and the biometric observations were recorded to study their association.

3.3.1. Insect-host Interaction and Symptomatology

The insect-host interaction studies were conducted in selected tree twigs. Freshly emerging side shoots were tagged and the different stages of gall infestation by EGW were documented by taking photographs at periodic intervals. Different degrees of galling on the leaflets, petioles and stem surface were observed to study the symptomatology.

3.3.2. Biometry Of Galled plant Parts

Leaf

Ten healthy and infested leaves were detached, and their weights were recorded in 'g'.

Petiole

Petioles of ten infested and uninfested leaves were collected and the length, girth and weight were recorded. Length of the petiole was measured from the base of the terminal leaflet to the other end using a scale and expressed in cm. The girth at the thickest part of the healthy as well as infested petioles was measured using twine and scale and expressed in cm. Healthy and infested petioles were detached, weighed and expressed in 'g'. Ten petioles in different damage scores as detailed in 3.1.1 were collected and kept in polypropylene covers and the number of wasps emerging from each score was recorded.

3.3.3 Histological studies

Hand sections were taken from the infested and uninfested petioles and leaves. The sections were observed under the microscope (5X). The change in the structure of the cells and the tissues in the infested plant parts were compared with the normal one and the changes were recorded by photo documentation. The galled petioles with galls at various stages of development were cut open and the different life stages of EGW were recorded by taking photographs.

3.3.4 Behavior of Adult EGW

In order to observe the activity, movement and ovipositional behavior of adult EGW with a view to understand the target sites for pesticide application, another experiment was done

Activity and movement of adult EGW

A pair of EGW was released into a petri plate and observed for 10 minutes. The activity and movement of the male and female insects were recorded separately.

3.3.5 Studies on Percentage Production of Healthy Sprouts in *E.stricta* under Field Conditions

Twelve *E.stricta* trees were selected and tagged in the Instructional Farm, Vellayani in order to assess the pattern of re growth after infestation by EGW. The selection of the trees was based on the height and branching pattern of the trees. Based on the height, the trees were divided into four groups.

Group 1 = 1-3 m height

Group 2 = 3-6 m height

Group 3 = greater than 6 m height

Group 4 = severely pruned

The number of healthy and infested sprouts was recorded weekly in each group consecutively for 53 weeks commencing from the 16th week of 2006(3rd week of April 2006). Percentage of healthy sprouts was calculated as given below.

Percentage of healthy sprouts = $H / H + I \times 100$

Where, I=Infested sprouts, H=Healthy sprouts

3.4 MANAGEMENT OF ERYTHRINA GALL WASP

Laboratory and field trials were conducted to determine the efficacy of chemical and botanical insecticides in controlling EGW.

3.4.1 Assessing Contact Toxicity of Chemical Insecticides

A laboratory experiment was conducted to evaluate the contact toxicity of selected insecticides on male and female EGW.

Design: CRD

Replications: 4

Treatments: 12

Insecticide		Dose	Quantity of commercial formulations	Company
Common name	Trade name			
Acephate	Twinguard 75SP	0.05%	0.06 g	Ghada Chemicals Ltd, Mumbai
Dimethoate	Tagor 30EC	0.05%	0.16 ml	Tropical Agro system (India)Ltd., Chennai
Triazophos	Hilaziphos 40EC	0.05%	0.12 ml	of Bayer Crop Science Ltd. Chennai
Chlorpyriphos	Tribon 20EC	0.05%	0.25 ml	Keminol Enterprises, Chennai

Lamdacyhalothrin	Command 5EC	0.05%	1 ml	Tropical Agro system (India) Ltd., Chennai
Imidacloprid	Confidor 17.8 SL	0.002%	0.010 ml	of Bayer Crop Science Ltd. Chennai
Carbaryl	Sevin 50WDP	0.1%	0.2 g	Bayer Crop Science Ltd. Chennai
Abamectin	Vertimec 1.9EC	0.002%	0.1 ml	Syngenta India Ltd, Coimbatore
Lufenuron	Match 5EC	0.001%	0.02 ml	Syngenta India Ltd, Coimbatore
Diafenthiruon	Pegasus 50 WP	0.01%	0.02 ml	Syngenta India Ltd, Coimbatore
Acetamiprid	Awad 20 SP	0.003%	0.030 g	Megamoney Organic Ltd. Hyderabad
Thiomethoxam	Actara 20 WG	0.002%	0.08 g	Syngenta India Ltd, Coimbatore

3.4.1.1 Preparation of stock solutions

The required quantities of the chemical insecticide formulations were measured using a pipette and the stock solutions were prepared in 100 ml acetone.

3.4.1.2 Preparation of dry film and release of test insect

The required lower concentrations of the insecticides were prepared by serial dilution of the stock solution with appropriate quantities of re distilled acetone. One ml each of the stock solution was carefully transferred to the test tube (15 x 2 cm) and the test tubes were rolled between two palms for spreading the solution evenly along the inner surface of the tube allowing evaporation of the solvent leaving a thin dry film of insecticide deposit. Freshly emerged one day old six males and six females of the insect were released separately into the treated test tubes. The experiment was conducted in a completely randomized design with three replications. Test tube treated inside with redistilled acetone served as control.

3.4.1.3 LC_{50} determination

Mortality of the males and females of the test insect were recorded after one hour of release. The percentage mortality was worked out and LC_{50} value computed using regression techniques by fitting the model $Y=a.e^{bx}$ where, x=concentration, b =regression coefficient, a= intercept

3.4.2 Determination of Systemic and Translaminar Effect of Selected Insecticides

3.4.2.1 Preparation and application of spray solution

The insecticides were measured using pipette and the spray fluids were prepared as described in 3.4.1.1 using water as solvent.Six uniformly gall infested leaves of *E.stricta* were collected at random and brought to the laboratory. The terminal leaflet, left lateral, right lateral and the petioles were detached and sprayed with the insecticides and kept for one hour for drying of the insecticide solution. The leaflets and the petioles were kept in separate perforated polypropylene covers and the emergence of wasps was recorded 1 DAS, 3DAS, 5DAS and 7 DAS

Replication-4

Design-CRD

Treatments

1.	Acephate	0.05%
2.	Dimethoate	0.05%
3.	Triazophos	0.05%
4.	Imidacloprid	0.002%

5. Acetamiprid 0.003%
6. Thiomethoxam 0.002%
7. Control

3.4.3. Efficacy of Botanicals in Managing EGW Infestation

The effect of different plant based insecticides (botanicals) against the attack of gall wasp was studied in the field. Uninfested healthy erythrina sprouts were selected (Plate 3). The sprouts were sprayed with the plant-based insecticides (botanicals). The interval between spraying of insecticides and the first appearance of galls was recorded.

Design-CRD

Replication-3

Treatments

1. Neem oil 2%
2. Neem oil garlic 2%
3. Garlic-soap 2%
4. Castor oil 2%
5. Karingotti oil 2%
6. Illuppai oil 2%
7. Pongamia oil 2%
8. Azadirachtin 0.002%
9. Control

3.4.3.1 Preparation of spray fluids

Plant oils

Five grams bar soap shavings were dissolved in one litre of water. To this soap solution 20 ml of neem oil / castor oil/ karingotti oil/ illupai oil/ pongamia oil was added to obtain 2 per cent emulsion.

Plate 3. A typical side shoot observed for evaluation of botanicals

Neem oil garlic emulsion

Twenty gram of sliced ordinary washing soap was dissolved in 500 ml luke warm water and it was mixed thoroughly with 100 ml neem oil and made up to am emulsion. One hundred gram of garlic was ground in 400 ml water and sieved through muslin cloth and mixed with neem oil emulsion to get 1:1 of stock solution. This was made up to 5 l and mixed thoroughly to get 2 per cent spray solution.

Garlic-soap emulsion

Five-gram bar soap shavings were added in 980 ml of water. To this soap solution 20 ml garlic extract was added to obtain 2 per cent garlic-soap emulsion.

Azadirachtin 0.002 per cent

Two ml of Neem Azal T.S supplied by E.I.D. Parry (India) Ltd., Chennai was added to 1 l of water to get the required concentration of Azadirachtin 0.002 per cent.

3.4.4 Field experiment

A field experiment was conducted during December 2006 at the Instructional farm, College of Agriculture, Vellayani. Infested Erythrina trees trailed with pepper vines with pepper berries where selected for the spraying. Based on the results from experiment 3.4.1 three treatments *viz.* carbaryl, imidacloprid and acephate were selectedfor the field treatment.Based on the results from experiment 3.4.2, triazophos and dimethoate (check) were selected. Based on the results from experiment 3.4.3, two botanicals viz. neemoil 2 per cent and neem oil garlic 2 per cent were selected. In addition to these, one common insecticide each from OP and pyrethroid classes viz. chlorpyrifos and lamda cyhalothrin were also included in the treatment. The fungicide carbendazim 0.2 per cent was also included as a combination treatment with acephate, dimethoate and imidacloprid.

Details of the trial

Design - RBD

Replications - 3

Treatments

1. Acephate 0.05 per cent + Carbendazim 0.2 per cent
2. Acephate 0.05 per cent
3. Dimethoate 0.05 per cent + Carbendazim 0.2 per cent
4. Dimethoate 0.05 per cent
5. Imidaclorprid 0.002 per cent + Carbendazim 0.2 per cent
6. Imidaclorprid 0.002 per cent
7. Lamdacyhalothrin 0.05 per cent
8. Chlorpyriphos 0.05 per cent
9. Carbaryl 0.1 per cent
10. Triazophos 0.05 per cent
11. Neem oil garlic 2 per cent
12. Neem oil 2 per cent
13. Untreated control

3.4.4.1 Preparation and Application of Spray Fluids

The required quantity of spray fluids for respective treatments was prepared as per the methods described under 3.4.1.1 and 3.4.2.1 using water as solvent. The spray was given when fresh side shoots were noticed in the trees. Observation on the production of the side shoots were recorded at the time of spraying (ATS), 2 weeks after spraying (WAS), and 4 WAS, 6WAS and 8WAS.

3.5 ESTIMATION OF TERMINAL RESIDUES IN DRY PEPPER BERRIES

The residues present in dry pepper berries collected at 1 day after spraying (DAS), 7 DAS and at harvest from the pepper plants trailed on erythrina trees sprayed with acephate 0.05 per cent, Chlorpyriphos 0.05 per cent, Triazophos 0.05 per cent, Dimethoate 0.05 per cent and Lamda cyhalothrin 0.05 per cent insecticides were estimated using standard procedure (Chozhan and Regupathy,1994).

RESULTS

4. RESULTS

4.1 POPULATION DYNAMICS OF ERYTHRINA GALL WASP

4.1.1 Emergence of EGW Population

Data on the weekly population of EGW, *Quadrastichus erythrinae* that emerged from leaflets (LL, TL, RL) and petioles of *Erythrina stricta* collected during the period from January 2006 to June 2007 are presented in Table 1.

4.1.1.1 Emergence of EGW population from galled left lateral leaflets

Emergence of EGW population from the LL (left lateral) leaflet showed a rise and fall during January 2006- March 2006(0.67-5.17), followed by a sudden significant hike (12.00) in the first week of April 2006. Subsequently there was a decrease in the population, reaching a low value in last week of April 2006 (0.67) and first week of May 06 (0.67). The population showed a significant peak in the second week of May 2006 (11.50), followed by a gradual decreasing upto the third week of June 06 (1.5-5.8). An increase in the population was observed again in the third and fourth week of June 06 (13.33, 11.50). The population further showed a varing trend upto third week of December 06 (0.33-7.67), and then increased during the last week of December 2006 (9.17). Again an increase in the population was observed in second week of April 2007 (11.50). The population further showed a gradual decrease reaching a low value in the first week of May 2007 (0.67). Again the population reached peak in the fourth week of May 2007 (12.67), followed by a sudden fall in last week of May 2007 (4.50). Population of the pest was high during the first week of June 2007 (26.83). The population decreased suddenly in the second week of June 2007 (0.17). Again, there was population rise and fall in the population in the alternate weeks.

The population observed during the first week of June 2007 (26.83) was significantly higher than that observed in third and fourth week of March 2006,

Table 1. Total population of EGW emerged from infested leaflets and petioles sampled for 78 weeks

Weeks	Month	Left lateral	Terminal leaf	Right lateral	Petiole
1	1-Jan-06	3.17	6.33	1.33	2.67
2	2-Jan-06	4.83	7.83	0.67	0.67
3	3-Jan-06	1.83	6.50	1.33	2.50
4	4-Jan-06	4.33	3.83	4.33	5.33
5	5-jan-06	3.50	2.33	11.00	9.17
6	1-feb-06	3.50	2.33	11.00	9.17
7	2-feb-06	5.17	5.00	5.67	8.67
8	3-feb-06	3.00	2.67	0.33	4.33
9	4-feb-06	3.00	2.67	0.33	4.33
10	1-mar-06	2.33	0.83	2.17	15.33
11	2-mar-06	1.67	3.67	1.67	10.50
12	3-mar-06	0.67	6.67	3.50	6.83
13	4-mar-06	0.67	1.00	0.83	2.50
14	1-Aprl-06	12.00	13.67	6.67	7.00
15	2-Aprl-06	1.17	2.67	5.17	4.00
16	3-Aprl-06	2.17	9.83	7.67	12.17
17	4-aprl-06	0.67	0.00	1.00	1.17
18	1-May-06	0.67	0.50	0.00	2.67
19	2-May-06	11.50	5.50	8.17	20.83
20	3-May-06	1.50	1.83	1.50	4.17
21	4-May-06	5.83	8.00	4.83	2.33
22	5-May-06	5.50	5.00	6.50	1.17
23	1-Jun-06	2.00	3.67	1.50	3.83
24	2-Jun-06	5.17	5.00	5.67	4.50
25	3-Jun-06	13.33	4.50	11.00	6.17
26	4-Jun-06	11.50	5.67	8.17	13.50

27	1-Jul-06	2.17	10.83	9.17	20.83
28	2-Jul-06	7.67	5.83	5.33	13.17
29	3-Jul-06	1.33	12.00	9.17	26.83
30	4-Jul-06	7.17	7.17	7.33	1.17
31	1-Aug-06	5.67	9.17	5.67	15.00
32	2-Aug-06	5.00	8.17	5.00	10.00
33	3-Aug-06	4.67	7.33	4.67	5.50
34	4-Aug-06	4.50	8.00	4.17	1.17
35	5-Aug-06	2.17	6.50	4.17	7.67
36	1-Sep-06	2.00	4.50	5.00	7.00
37	2-Sep-06	2.17	5.17	3.33	5.00
38	3-Sep-06	1.83	2.83	2.83	1.50
39	4-Sep-06	2.00	2.00	2.00	3.83
40	1-Oct-06	3.67	4.00	2.00	7.00
41	2-Oct-06	3.67	7.50	3.67	11.00
42	3-Oct-06	0.50	0.50	0.33	14.67
43	4-Oct-06	2.00	5.00	3.00	10.00
44	5-Oct-06	5.67	6.67	4.50	6.67
45	1-Nov-06	5.83	7.67	6.67	1.50
46	2-Nov-06	1.33	3.00	3.50	24.17
47	3-Nov-06	3.00	6.00	3.17	26.67
48	4-Nov-06	2.00	3.00	2.00	13.83
49	1-Dec-06	2.00	1.00	1.00	3.00
50	2-Dec-06	0.33	1.17	1.17	2.00
51	3-Dec-06	5.00	8.00	5.00	11.67
52	4-Dec-06	9.17	18.67	9.17	25.50

53	1-Jan-07	5.67	11.33	6.17	19.00
54	2-Jan-07	3.67	8.33	3.67	13.50
55	3-Jan-07	3.50	4.83	3.50	7.50
56	4-Jan-07	7.33	4.67	2.67	8.00
57	5-Jan-07	5.50	9.33	3.83	7.50
58	1-Feb-07	5.00	5.00	4.00	9.33
59	2-Feb-07	6.33	4.83	3.67	10.00
60	3-Feb-07	2.00	2.00	2.00	6.00
61	4-Feb-07	8.00	7.00	5.00	1.17
62	1-Mar-07	4.33	3.83	1.83	4.17
63	2-Mar-07	2.00	1.00	2.00	8.50
64	3-Mar-07	3.00	3.00	2.50	12.50
65	4-Mar-07	4.00	6.33	5.83	17.50
66	1-Aprl-07	4.00	8.17	4.00	17.50
67	2-Aprl-07	11.50	15.50	9.67	25.67
68	3-Aprl-07	2.67	1.50	4.00	8.83
69	4-Aprl-07	2.17	10.83	9.33	9.00
70	1-May-07	0.67	0.50	0.00	9.17
71	2-May-07	1.33	0.00	1.00	9.50
72	3-May-07	6.00	9.00	4.83	10.17
73	4-May-07	12.67	6.67	7.17	10.83
74	5-May-07	4.50	5.00	5.17	13.83
75	1-Jun-07	26.83	30.67	12.00	12.50
76	2-Jun-07	0.17	2.67	2.33	2.00
77	3-Jun-07	4.50	5.00	5.17	13.83
78	4-Jun-07	8.50	13.67	9.83	6.67
CD = 0.469					

third week of October 2006, second week of December 2006, first week of May 2007 and in the second week of June 2007.

4.1.1.2 Emergence of EGW population from galled Terminal Leaf

The emergence of EGW from the terminal leaf during January 2006 to March 2006 showed slight rise and fall in the number per leaflet ranging from 0.83-7.83. An increase in the population of the pest was recorded in the first week of April 2006 (13.67). The population then showed a sudden decline (2.67), followed by a gradual increase. No population was recorded in the last week of April 2006, subsequently the emergence of the wasp ranged from 0.5-8.00 till the – week of June 2006. A significant increase in the population was recorded during the 1st week of July 2006 (10.83). Comparatively a higher population of the wasp was recorded from the third week of July 06 till the last week of August 2006 (6.5-12.00). The population was low during the month of September 2006 (2.00-5.17). With the exception of low number of EGW recorded during the third week of October 2006 (0.5), the population of the pest was comparatively high during the month and November, population ranging from 3.00-7.67 per leaflet. The population was low during the first (1.00) and second week of December 2006. However higher population of the pest was recorded from the third week of December to second week of January 2007 (8.33-18.67). Except for the high population observed during the fifth week of January 2007 (9.33) the population of the pest ranged from 2.00 to 8.017 from third week of February 2007 to first week of April 07. This was followed by significant increase in population during the third week of April 2007 (10.83). A sudden drop was noticed in the emergence of the pest in the last week of April and first week of May 2007 (0.00, 0.50). Again there was an increase in the population (8.00), during the fourth week of May 2007. The number of wasp that emerged during the fourth and fifth week of May was 8.00 and 5.00 respectively. A hike in the population was noted in the first week of June 2007 (30.67), which was followed by a sharp drop during the second (2.67) and third (5.00) week of June 2007. This was followed by a significant rise in the population during the last week of June 2007(13.67).

The population observed during the first week of June 2007 was significantly higher than that observed in fourth week of April 2006, first week of May 2006, third week of October 2006, first week of December 2006, first week of March 2006, first week of May 2007 and second week of May 2007.

4.1.1.3 Emergence of EGW population from galled right lateral

The adult EGW population recorded from the right lateral showed a gradual increase, reaching a higher value during the last week of January 2006 and first week of February 2006 (11.00). This was followed by gradual decrease in the population reaching lower values in last two weeks of February 2006. This was followed by rise and fall in the population in the alternate weeks until the second week of June 2007. The population reached a peak value in the third week of June 2006, followed by a gradual decreasing phase until the third week of October 2006 (0.33). Again there was a population rise and fall in the alternate weeks. The population reached a peak value in the last week of December 2006 (9.17), followed by gradual diminishing phase until the first week of March 2007 (1.83). From then onwards the population showed an increase, reaching a peak value in the second week of April 2007 (9.67), which was followed by another hike in population during the last week of April 2007 (9.33). There was a sharp fall in the first week of May 2007 (0.00). Later it started building up steadily reaching a peak value in the first week of June 2007 (12.00). Again there was a gradual and steady increase in the emergence. The population observed during the first week of June 2007 was significantly higher than that observed in the second week of January 2006, third and fourth week of February 2006, fourth week of March 2006, first week of May 2006, third week of October 2006 and first week of May 2007.

4.1.1.4 Emergence of EGW population from galled petioles

The population of adult EGW showed a gradual increase in the first few weeks of January 2006, reaching a maximum value in the fifth and sixth standard week of 2006. Then a steady decrease in population from petiole was observed in the last week of February 2006. The population was high in the first week of March 2007 (15.33), and then decreased steadily until the last week of March 2006 (2.50). Again there was population rise and fall in the following two weeks. The population recorded in the second week of May 2006 (20.83) was high, followed by a gradual and steady decrease in the population reaching a low value in the fifth week of May 2006 (1.17). Later the population increased gradually until the first week of July 2007 (20.83). This was followed by a fall in the population (13.17). A hike in the population was observed in the third week of July 2006 (26.83). This was followed by sharp fall and rise in the alternative weeks until the first week of November 2005 when the population was only 1.50. An increase in the population was noticed in the first two weeks of November 2006 (24.17 and 26.67). This was again followed by yet another phase of slight fall and the population followed a diminishing pattern till the second week of December 2006. The population started building up gradually and reached a peak value in the last week of December 2006 (25.50). The population again decreased until the last week of February 2007 (1.17). This was followed by a gradual and steady increase in the EGW population which reached the maximum value (25.67) in the second week of April 2007. There was a sudden fall in the third week of April 2007, followed by a more or less constant pattern in the population. Again there was a population rise and fall in the alternative weeks reaching a very low value (2.00) in the second week of January 2007. Later the population increased gradually and this was again followed by rise and fall in the last two weeks of June 2007.

4.1.1.5 Male and female EGW population

The percentage of male and female EGW that emerged during the period of study is illustrated in Fig. 1. The male EGW (58.8 per cent) emerged during the period exceeded the female emergence (41.2 per cent).

4.1.1.6 Weight of leaflets and petioles

The maximum extent of damage indicated by weight of leaflets was produced in the left lateral (2.48g) followed by petiole, terminal leaf and right lateral with pooled mean weights of 2.01g, 1.61g and 1.58g respectively. The data is presented in Table 2.

Mean weight of left laterals sampled for observing the extent of gall infestation ranged from 0.83g to 4.79g. The weight of the left lateral damaged by EGW was the highest in the 78 th week and minimum in the fifth and sixth week.

The biomass of the infested terminal leaflets ranged from 0.55g to 3.38g. The highest intensity of leaf galls was produced in the 76th week and the lowest biomass was recorded during fifth and sixth weeks.

The mean weight of right lateral leaflets sampled for observing extent of galls produced by EGW ranged from 0.66g to 3.05g. The highest damage by EGW on the right lateral leaflets was produced during the 10th and 76th weeks and the lowest incidence of EGW on right lateral samples was observed in during the 20th and 64th weeks.

The weekly variation in the mean weight of gall infested petioles caused by EGW sampled for 78 weeks ranged from 0.98g to 4.76g. The maximum weight of gall infested petioles was observed in the 29th week and the lowest level of gall infestation in petiole samples was noticed in the 15th week.

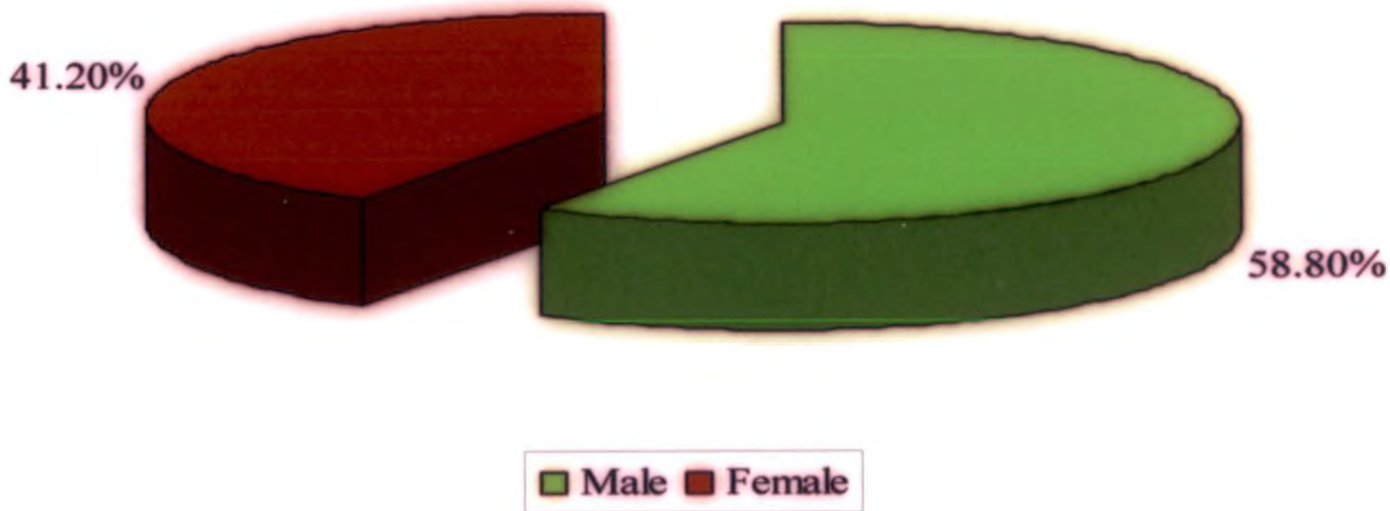


Fig. 1. Percentage of male and female EGW emerged from the leaflets and petiole sample collected during January 06 to June 07

Table 2. Weekly variation in the biomass of galled leaflets and petioles of *E.stricta* sampled for 78 weeks

Week	Month	Mean weight (gram) of plant parts infested by EGW			
		Left Lateral	Terminal Leaf	Right Lateral	Petiole
1	1-Jan-06	2.81	1.68	1.85	3.23
2	2-Jan-06	3.84	2.77	2.68	1.36
3	3-Jan-06	2.81	1.68	1.85	1.45
4	4-Jan-06	3.23	2.16	2.11	2.75
5	5-jan-06	0.83	0.55	0.78	1.35
6	1-feb-06	0.83	0.55	0.78	1.35
7	2-feb-06	1.66	1.43	1.02	1.35
8	3-feb-06	2.89	2.03	1.47	1.07
9	4-feb-06	2.97	1.66	1.26	1.07
10	1-mar-06	4.51	3.38	3.05	3.31
11	2-mar-06	3.59	1.90	1.88	2.20
12	3-mar-06	1.54	1.10	1.27	1.38
13	4-mar-06	2.89	2.03	1.47	1.45
14	1-Aprl-06	3.05	1.56	1.44	0.99
15	2-Aprl-06	1.40	0.77	0.68	0.98
16	3-Aprl-06	2.71	1.54	1.37	1.77
17	4-aprl-06	2.97	1.66	1.26	1.36
18	1-May-06	2.45	1.51	1.23	1.73
19	2-May-06	0.97	0.75	0.86	1.77
20	3-May-06	1.00	0.65	0.66	1.07
21	4-May-06	2.09	1.16	1.21	2.03
22	5-May-06	1.66	1.43	1.02	1.73
23	1-Jun-06	3.04	1.64	1.23	1.98
24	2-Jun-06	1.66	1.43	1.02	1.07
25	3-Jun-06	2.53	1.63	2.47	1.38

26	4-Jun-06	2.27	1.54	1.39	2.23
27	1-Jul-06	2.71	1.54	1.37	1.77
28	2-Jul-06	3.30	2.01	2.20	2.85
29	3-Jul-06	3.97	2.45	2.85	4.76
30	4-Jul-06	1.44	1.64	2.54	1.98
31	1-Aug-06	2.09	1.16	1.21	3.31
32	2-Aug-06	3.30	2.01	2.20	2.20
33	3-Aug-06	3.12	2.05	1.86	2.75
34	4-Aug-06	3.12	2.05	1.86	2.42
35	5-Aug-06	3.23	2.16	2.11	0.99
36	1-Sep-06	1.54	1.10	1.27	2.35
37	2-Sep-06	2.81	1.68	1.85	1.32
38	3-Sep-06	3.04	1.64	1.23	2.42
39	4-Sep-06	1.65	0.96	0.99	1.35
40	1-Oct-06	2.81	1.68	1.85	2.35
41	2-Oct-06	3.84	2.77	2.68	2.25
42	3-Oct-06	2.23	2.10	2.47	3.31
43	4-Oct-06	2.81	1.68	1.85	2.20
44	5-Oct-06	2.01	1.81	1.89	2.75
45	1-Nov-06	3.27	1.89	1.58	1.80
46	2-Nov-06	3.59	1.90	1.88	2.79
47	3-Nov-06	3.23	2.16	2.11	2.37
48	4-Nov-06	3.59	1.90	1.88	2.85
49	1-Dec-06	2.58	1.63	1.71	2.87
50	2-Dec-06	1.19	1.10	0.82	1.39
51	3-Dec-06	3.30	2.01	2.20	2.25
52	4-Dec-06	2.51	1.39	1.43	2.66

53	1-Jan-07	3.97	2.45	2.85	1.77
54	2-Jan-07	3.84	2.77	2.68	2.85
55	3-Jan-07	1.54	1.10	1.27	1.38
56	4-Jan-07	2.08	1.57	1.38	1.35
57	5-Jan-07	3.30	2.01	2.20	1.38
58	1-Feb-07	2.08	1.57	1.38	2.20
59	2-Feb-07	2.08	1.57	1.38	2.20
60	3-Feb-07	1.65	0.96	0.99	2.35
61	4-Feb-07	1.38	1.01	1.24	1.33
62	1-Mar-07	1.54	1.10	1.27	1.98
63	2-Mar-07	1.00	0.65	0.66	1.35
64	3-Mar-07	1.40	0.77	0.68	2.11
65	4-Mar-07	0.83	0.55	0.78	1.62
66	1-Aprl-07	0.83	0.55	0.78	1.62
67	2-Aprl-07	2.51	1.39	1.43	2.66
68	3-Aprl-07	1.99	0.96	0.94	1.35
69	4-Aprl-07	2.71	1.54	1.37	1.35
70	1-May-07	2.45	1.51	1.23	2.25
71	2-May-07	1.19	1.10	0.82	2.25
72	3-May-07	2.09	1.16	1.21	1.77
73	4-May-07	1.46	1.37	1.17	2.20
74	5-May-07	2.08	1.57	1.38	2.12
75	1-Jun-07	3.52	2.33	2.07	2.11
76	2-Jun-07	4.51	3.38	3.05	3.23
77	3-Jun-07	2.08	1.57	1.38	2.12
78	4-Jun-07	4.79	2.63	2.59	2.35
CD(0.05)	0.28				

4.1.1.7 Study in gall number

Weekly variations in the number of galls produced by the EGW on the left lateral, terminal leaf, right lateral and petiole due to infestation by EGW are presented in Table 3.

The maximum number of galls was noticed in the left lateral (30.40), followed by the right lateral, terminal leaf and petiole with pooled mean gall no of 21.12, 19.64 and 3.58.

The maximum number of gall production by EGW in the left lateral was noticed in the week 11th and 46th standard weeks (78.33). Mean number of galls in the left lateral sampled for 78 weeks ranged from 12.17 to 78.33. The number of galls in the left lateral was lowest in the 5th, 6^{th,} 65th and 66th standard weeks with the same gall number of 12.17 per leaflet.

The number of galls produced in the terminal leaflets ranged from 6.67 to 38.17. The highest gall no in the terminal leaf was noticed in the 11th , 46th and 48th standard weeks of 2005 (38.17) and the lowest gall number was observed in the terminal leaflets sampled during 21st, 31st and 72nd standard week with a mean gall number of 6.67 per leaflet.

The mean number of galls produced by EGW in the right lateral leaflets sampled for 78 weeks ranged from 4.83 to 50.83. The highest gall number produced by EGW on the right lateral leaflets was observed during the 30th standard week of 2005 with a mean number of 50.83, and the lowest gall number produced by EGW on right lateral leaflets was observed in the standard week 15 of 2006 (4.83).

The weekly variation in the mean intensity score (MIS) of galls produced in the petioles by EGW sampled for 78 weeks ranged from 0.83 to 5.67. The maximum score value of galled petioles was recorded in the 11th, 29th, 32nd, 43rd, 58th, 59th and 73rd week (5.67) in all the weeks and the lowest number of galls was noticed in petioles during the 21st week with a mean no of 0.83.

Table 3. Number of galls in leaflets and mean intensity score in petioles of *E. stricta* produced by EGW sampled for 78 weeks

Weeks	Month	Number of galls in			MIS in Petiole
		Left Lateral	Terminal Leaf	Right Lateral	
1	1-Jan-06	41.50	20.33	24.83	3.50
2	2-Jan-06	32.50	17.33	19.33	1.17
3	3-Jan-06	41.50	20.33	25.00	2.33
4	4-Jan-06	33.17	30.17	28.67	3.33
5	5-jan-06	12.17	13.17	13.50	3.17
6	1-feb-06	12.17	13.17	13.50	3.17
7	2-feb-06	27.50	26.00	21.50	3.17
8	3-feb-06	31.33	29.33	18.00	4.00
9	4-feb-06	29.17	12.67	10.50	4.00
10	1-mar-06	33.33	18.50	25.33	4.33
11	2-mar-06	78.33	38.17	49.17	5.67
12	3-mar-06	24.83	22.67	20.50	4.17
13	4-mar-06	31.33	29.33	18.00	2.33
14	1-Aprl-06	37.67	22.83	16.00	3.00
15	2-Aprl-06	27.33	7.00	4.83	1.50
16	3-Aprl-06	27.83	11.33	14.83	4.33
17	4-aprl-06	29.17	12.67	10.50	1.17
18	1-May-06	31.50	19.17	9.00	5.50
19	2-May-06	18.50	17.50	15.00	4.33
20	3-May-06	24.00	14.17	16.50	4.00
21	4-May-06	18.50	6.67	5.33	0.83
22	5-May-06	27.50	26.00	21.50	3.33
23	1-Jun-06	35.17	19.83	14.17	3.17
24	2-Jun-06	27.50	26.00	21.50	4.00
25	3-Jun-06	24.17	18.83	27.50	1.83
26	4-Jun-06	25.83	20.50	15.00	2.33

27	1-Jul-06	27.83	11.33	14.83	4.33
28	2-Jul-06	36.67	23.50	23.67	3.33
29	3-Jul-06	45.00	33.67	32.00	5.67
30	4-Jul-06	30.67	32.17	50.83	4.00
31	1-Aug-06	18.50	6.67	5.33	4.33
32	2-Aug-06	36.67	23.50	23.67	5.67
33	3-Aug-06	25.50	17.67	12.83	3.33
34	4-Aug-06	25.50	17.67	12.83	2.00
35	5-Aug-06	33.17	30.17	28.67	3.00
36	1-Sep-06	24.83	22.67	20.50	3.67
37	2-Sep-06	41.50	20.33	24.67	1.67
38	3-Sep-06	35.17	19.83	14.17	2.00
39	4-Sep-06	34.83	19.67	24.50	3.00
40	1-Oct-06	41.50	20.33	24.83	3.67
41	2-Oct-06	32.50	17.33	19.33	3.67
42	3-Oct-06	33.33	34.00	35.17	4.33
43	4-Oct-06	41.50	20.33	24.50	5.67
44	5-Oct-06	21.83	22.50	28.50	3.33
45	1-Nov-06	44.17	26.00	23.17	3.33
46	2-Nov-06	78.33	38.17	49.17	4.00
47	3-Nov-06	33.17	30.17	28.67	3.67
48	4-Nov-06	78.33	38.17	49.17	3.33
49	1-Dec-06	35.83	21.50	25.00	4.67
50	2-Dec-06	24.50	10.83	13.00	1.83
51	3-Dec-06	36.67	23.50	23.67	3.67
52	4-Dec-06	31.67	20.67	22.83	4.83

53	1-Jan-07	45.00	33.67	32.00	4.33
54	2-Jan-07	32.50	17.33	19.33	3.33
55	3-Jan-07	24.83	22.67	20.50	4.17
56	4-Jan-07	15.67	14.17	28.83	3.17
57	5-Jan-07	36.67	23.50	23.67	4.17
58	1-Feb-07	15.67	14.17	28.83	5.67
59	2-Feb-07	15.67	14.17	28.83	5.67
60	3-Feb-07	34.83	19.67	24.50	3.67
61	4-Feb-07	11.83	8.33	15.50	1.83
62	1-Mar-07	24.83	22.67	20.50	3.17
63	2-Mar-07	24.00	14.17	16.50	3.17
64	3-Mar-07	27.33	7.00	4.83	3.67
65	4-Mar-07	12.17	13.17	13.50	4.33
66	1-Aprl-07	12.17	13.17	13.50	4.33
67	2-Aprl-07	31.67	20.67	22.83	4.83
68	3-Aprl-07	16.50	7.50	10.00	3.17
69	4-Aprl-07	27.83	11.33	14.83	3.17
70	1-May-07	31.50	19.17	9.00	3.67
71	2-May-07	24.50	10.83	13.00	3.67
72	3-May-07	18.50	6.67	5.33	4.33
73	4-May-07	24.83	18.83	21.00	5.67
74	5-May-07	15.67	14.17	28.83	2.67
75	1-Jun-07	33.17	22.00	18.17	3.67
76	2-Jun-07	33.33	18.50	25.33	3.50
77	3-Jun-07	15.67	14.17	28.83	2.67
78	4-Jun-07	32.50	14.50	24.17	3.67
CD(0.05)	3.4				

4.1.2 Influence of Weather Parameters on Pest Emergence

The data on total population when correlated with maximum and minimum relative humidity, maximum and minimum temperature and rainfall of 2006 and also with the data of weather parameters of the preceding four weeks are presented in Table 4.

The data on total population of EGW did not show any correlation with the weather parameters. The data on emergence of male population from the right lateral showed positive correlation with minimum temperature (0.2683*) and negative correlation with maximum relative humidity (-0.2468*). The male population from left lateral showed negative correlation with maximum relative humidity (-0.2290*)

When population fluctuation was compared with data on the weather parameters prevailed during the previous week, the male population that emerged from the right lateral leaflet showed positive correlation with minimum temperature (0.2206*) and minimum relative humidity (0.2405*) and negative correlation with maximum relative humidity (-0.2715*).

When the data was correlated with the weather parameters that prevailed during the week 14 days(2 weeks) before the population of male EGW emerged from left lateral showed positive correlation with minimum temperature (0.3247**) the males from right lateral also showed positive correlation with minimum temperature (0.2508*) and minimum relative humidity (0.3200**). The total male population emerged from all leaflets also showed positive correlation with minimum temperature (0.2782*).

The data on population when compared with the weather parameters of the week 21 days before, the males from right lateral, terminal leaf and total males from all leaflets showed positive correlation with minimum temperature (0.3646**),(0.2500*) ,(0.284*). However there was no correlation between female population and any of the weather parameters.

Table 4. Correlation coefficient of weather parameters during the period of study with population of EGW

Correlation coefficient of weather parameters during the current week with the data on population emerged from different plant parts of *E.stricta* sampled for 78 weeks						
Weather parameter	Leaf Total Male	Leaf Total Female	GT	Petiole Male	Petiole Female	Petiole total
Temp max	-0.1147	-0.0395	-0.0905	0.0786	0.0094	0.0510
Temp min	0.1897	-0.0125	0.1162	-0.0365	0.0734	0.0118
Rh-max	-0.2027	-0.0830	-0.1656	0.0663	0.0209	0.0489
Rh-min	0.2041	0.0894	0.1693	-0.0041	0.0049	0.0249
Rainfall	0.0342	-0.0582	-0.0030	0.1450	0.0833	0.1243
Correlation coefficient of weather parameters during the previous one week with the data on population emerged from different plant parts of *E.stricta* sampled for 78 weeks						
Weather parameters	Leaf Total Male	Leaf Total Female	GT	Petiole Male	Petiole Female	Petiole total
Temp max	-0.0645	-0.0185	-0.0493	0.0416	-0.0539	-0.0496
Temp min	0.1215	-0.1257	0.0239	0.1254	0.1253	0.1318
Rh-max	-0.1754	0.0122	-0.1071	-0.2142	-0.1360	-0.1895
Rh-min	0.1273	-0.0560	0.0575	-0.0769	0.1148	0.0098
Rainfall	0.1314	0.1072	0.1303	-0.0852	0.0085	-0.0467
Correlation coefficient of weather parameters during the week 14 days before with the data on population emerged from different plant parts of *E.stricta* sampled for 78 weeks						
Weather parameters	Leaf Total Male	Leaf Total Female	GT	Petiole Male	Petiole Female	Petiole total
Temp max	0.0309	-0.0263	0.0085	-0.0487	-0.0777	-0.0644
Temp min	0.2782*	0.0428	0.1967	0.0985	0.1692	0.1358
Rh-max	-0.0193	0.0165	-0.0052	0.0978	0.0251	0.0696
Rh-min	0.1940	-0.0066	0.1215	0.0715	0.0808	0.0794
Rainfall	-0.0194	-0.0536	-0.0354	0.0193	0.0963	0.0554

Correlation coefficient of weather parameters during the week 21 days before, with the data on population emerged from different plant parts of *E.stricta* sampled for 78 weeks						
Weather parameters	Leaf Total Male	Leaf Total Female	GT	Petiole Male	Petiole Female	Petiole total
Temp max	-0.0542	0.0044	-0.0328	-0.1143	-0.1354	-0.1298
Temp min	0.2843*	0.0176	0.1898	0.0875	0.0016	0.0527
Rh-max	-0.0888	0.0443	-0.0379	0.0153	-0.0291	-0.0042
Rh-min	0.0697	-0.0879	0.0069	-0.1100	-0.0248	-0.0767
Rainfall	-0.0310	-0.0706	-0.0502	0.0020	0.1443	0.0671
Correlation coefficient of weather parameters during the week 28 days before, with the data on population emerged from different plant parts of *E.stricta* sampled for 78 weeks						
Weather parameters	Leaf Total Male	Leaf Total Female	GT	Petiole Male	Petiole Female	Petiole total
Temp max	0.0091	0.0541	0.0291	0.0304	0.0043	0.0200
Temp min	0.2536*	0.0135	0.1684	-0.0922	-0.1259	-0.1123
Rh-max	0.0212	0.0783	0.0200	0.1668	0.2105	0.1953
Rh-min	0.0874	-0.0781	0.0224	0.0234	0.0382	0.0313
Rainfall	0.1272	-0.0008	0.0811	0.3342**	0.3767**	0.3707

* Significant at 5%
** Significant at 1%
GT=grant total

4.1.3 Correlation Between Population of EGW and Weight and Number of Galls

The data on male, female and total population of EGW were correlated with the weight of the LL, RL, TL and petioles and the number of galls and the result is presented in Table 5.

The data on total population emerged from TL showed positive correlation with mean weight of TL (0.2288*). Similarly the mean weight of the petioles showed positive correlation with male population (0.3905**), female population (0.3882**) and total population (0.4094**).

4.2 IMPACT OF EGW INFESTATION ON FOLIAGE PRODUCTION IN *E.STRICTA*

During the period of observation for eighteen months three distinct damage cycles of EGW could be identified .Each cycle lasted for approximately six months with a stage of sprouting, active foliage growth, galling, peak defoliation and a final leafless stage (Fig. 2). This was again followed by appearance of new sprouts and the cycle continued. In certain trees the peak defoliation stage was followed by secondary infection by fungus causing bark rot and death.

4.3 NATURE OF DAMAGE

4.3.1 Insect-Host Interaction and Symptomatology

The insect host interaction studies were conducted in selected tree twigs. Freshly emerging side shoots were tagged and the different stages of gall infestation by EGW were documented by taking photographs at periodic intervals (Plate 4). Galls were found on leaves, petioles, buds and stem. Galls when formed on tender leaves failed to attain the normal shape and size. The leaf blade increased in thickness. The galls were not sessile like other wasp galls. In

Table 5. Correlation coefficient of population of EGW emerged from leaflets and petioles of *E. stricta* with leaf and petiole weights and the number of galls

Plant Parameter	Male	Female	Total population
Terminal leaf Weight	0.2108*	0.2184*	0.228*
Terminal leaf Gall No:	-0.0143	-0.0120	-0.0143
Lateral leaf Weight	-0.0166	0.1133	0.0389
Lateral leaf Gall No:	-0.0696	-0.0371	-0.0205
Right lateral leaf Weight	0.1139	-0.0800	-0.0372
Right lateral leaf Gall No:	0.0143	-0.0874	-0.0333
Petiole Weight	0.3905**	0.3882**	0.4094**
Petiole grade	0.4527**	0.4417**	0.4708**

* Significant at 5%
** Significant at 1%

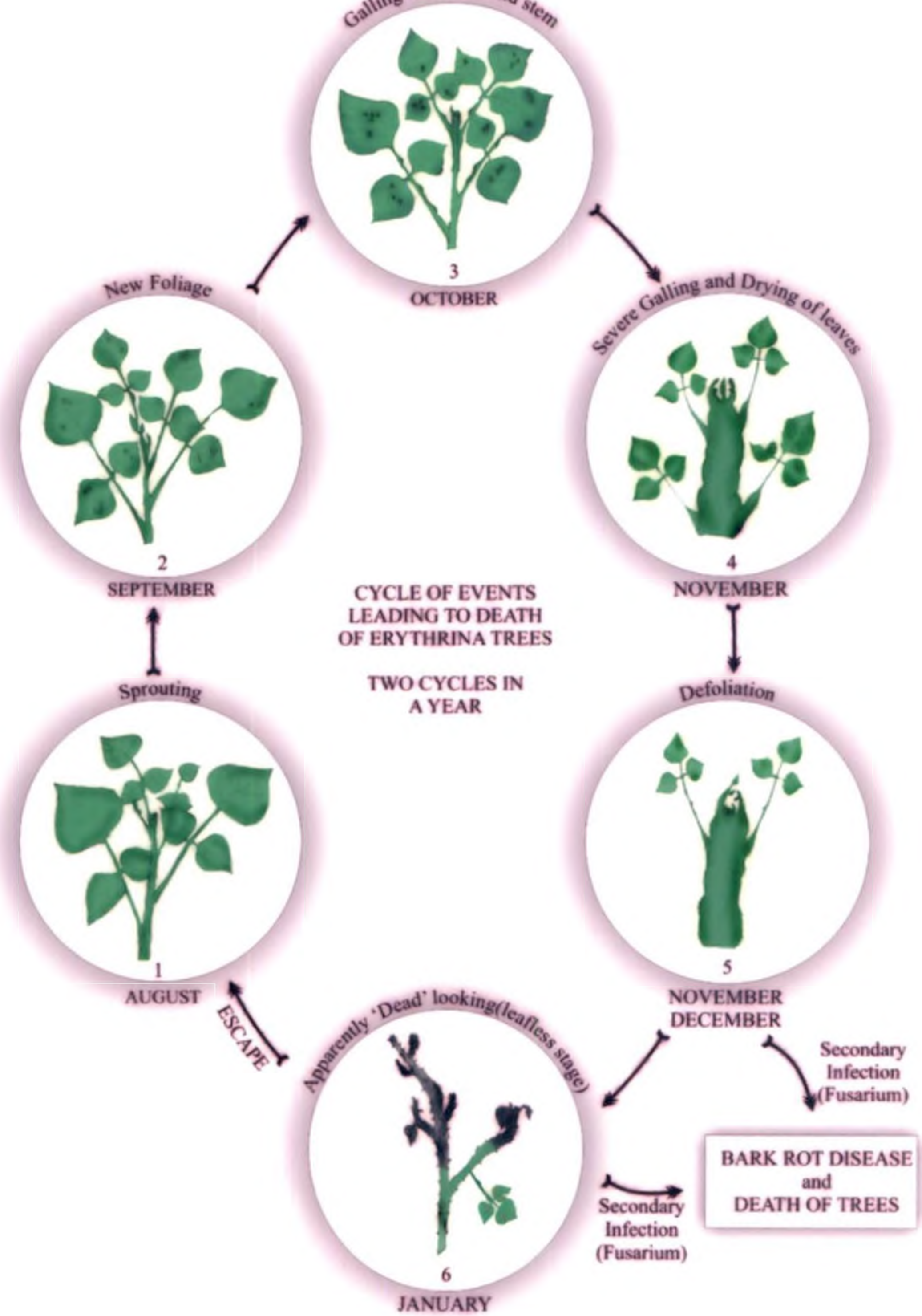
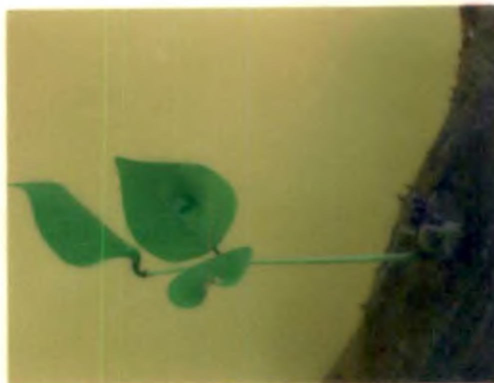


Fig. 2. Cyclic events of foliage production in *E.stricta* and complete defoliation by EGW leading to death of trees.

Initiation of sprout



Emergence of first leaf

Appearance of galls on new leaves

Advancing symptom of gall infestation

Defoliation due to severe galling

Apparently dead looking stage

Plate 4. Stages of Gall formation

leaves, the galls were pouch shaped when present singly. Many galls combined together to form a fleshy succulent mass. The galls when formed on the petioles, became more or less swollen and curved increasing the girth of the petioles. When galls were formed on the developing buds, the elongation of the internodes was detained. In all the cases the galls were solid and enclosed a single wasp larva.

The larva feeds with in the gall cavity lined by nutritive tissues ,completed its life cycle and emerged as winged adult cutting an exit hole. The exit holes were present abundantly on petioles and tender stem acted as entry points for secondary pathogens. The pathogen complex caused rotting of the bark leading to shredding and peeling of the bark. The shredded bark finally detach from the plant and fall off to the base resulting in the death of the plant (Plate 10).

4.3.2 Biometry of Galled Plant Parts

Results on the degree of damage in various plant parts due to galling by EGW presented in Table 6 indicated that the weight of LL, TL and RL increased after the infestation by EGW. When the weights of normal and infested terminal leaflets were compared, the infestation by EGW increased the weight of leaflets by two fold (Plate 5a and 5b). Similarly the weight (2.44 ± 1.23g) and girth(2.64 ± 0.91cm) of the infested petiole were almost double that of the uninfested petioles ,the weight (1.37 ± 0.304g) and girth ($1.14 \pm .206$cm)(Plate 5c). The length of the petiole decreased considerably after the infestation by EGW. The normal length of the petiole (25.27 ± 2.65cm) was reduced to one third (8.59 ± 4.84), on account of gall infestation.

The girth, weight and emergence of EGW from the respective scores of the petiole are presented in Table 7. The girth of the petioles increased with increase in the score. The girth of the petiole in score '9' was the greatest (4.03 ± 0.17). Similarly the weight of the petioles also increased proportionally with

Table 6. Biometric observations of normal and galled plant parts

Plant part	Parameter	Normal	Infested
Left lateral	Weight (g)	0.82 ± 0.28	1.82 ± 0.81
Right lateral	Weight (g)	0.86 ± 0.30	1.54 ± 0.76
Terminal leaf	Weight (g)	1.63 ± 0.51	3.40 ± 1.42
Petiole	Weight (g)	1.37 ± 0.31	2.44 ± 1.22
Petiole	Girth (cm)	1.14 ± 0.21	2.64 ± 0.91
Petiole	Length (cm)	25.27 ± 2.65	8.59 ± 4.84

Mean of ten observations

Table 7. The girth and weight of petioles with 0 to 9 damage indices and the number of EGW emerged from them.

Score	Girth (cm)	Weight (g)	Emergence no/petiole
0	1.14 ± 0.21	1.37 ± 0.30	0
1	1.31 ± 0.23	1.30 ± 0.65	7.6 ± 1.90
3	1.82 ± 0.18	2.32 ± 0.73	15.5 ± 4.95
5	2.31 ± 0.26	2.99 ± 1.25	20.5 ± 6.80
7	2.44 ± 0.72	3.03 ± 1.12	22.2 ± 9.64
9	4.03 ± 0.17	3.64 ± 1.09	37.3 ± 14.29

Mean of ten observations

Plate 5a. Normal and infested trifoliate leaf

Plate 5b. Three leaflets and petiole separated from
a severely galled trifoliate leaf

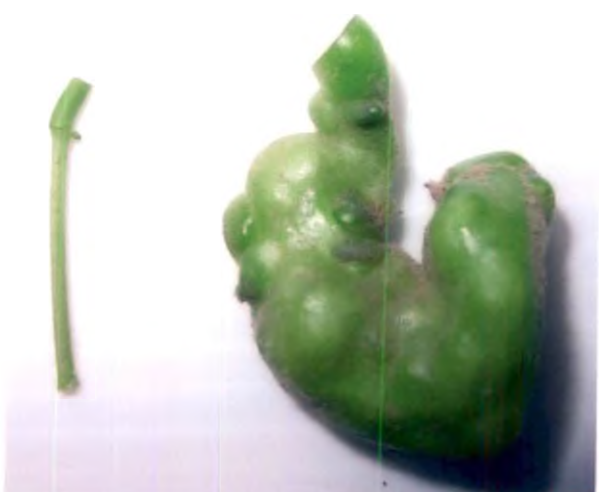


Plate 5c. Comparison of normal and severely infested *E.stricta* petioles

Plate 6a. Cut sections of *E.stricta* stem showing the galleries made by EGW

Plate 6b. Section of the *E.stricta* petiole showing galleries made by EGW

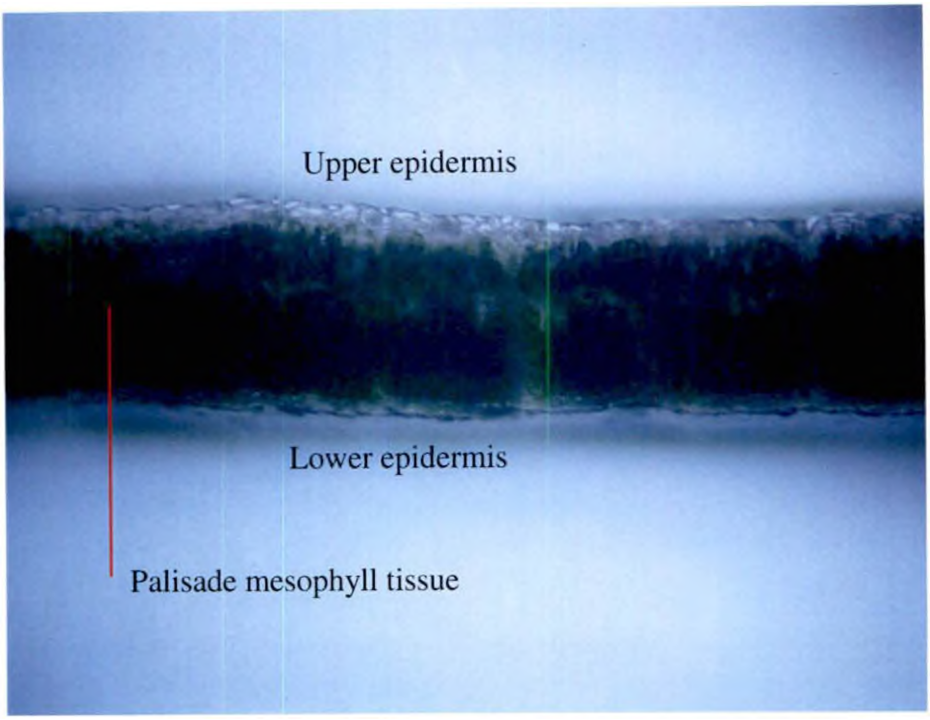
respect to the increase in the score. The emergence of EGW was greatest in the score '9' (37.3 ± 14.29).

4.3.3 Histological Studies

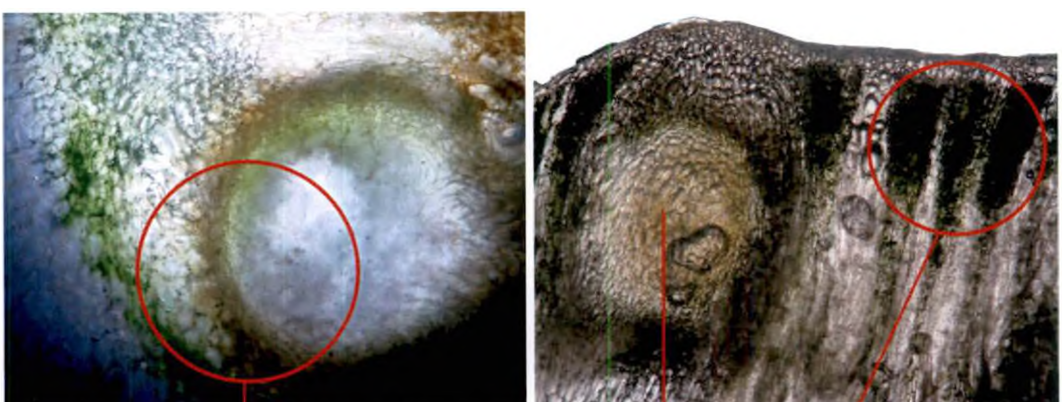
The thickness of the leaf lamina increased as a result of galling. The palisade tissues were found degenerating and the perpendicular arrangement of palisade tissues were altered (Plate 6). The green colour of the palisade mesophyll tissues was not seen.

Cross section of healthy petiole of *E.stricta* showed the vascular bundles and the ground tissues (Plate 7a). In the cross section of galled petioles, the vascular bundles were observed compressed and the ground tissues were found degenerating leading to the formation of hollow pith (Plate 7b). The gall cavity was lined by closely packed cells which had traces of chlorophyll. The gall cavity was filled with a nutritive layer devoid of chlorophyll. The cells near the galls lost their shape and their size was either increased or altered.

The hand sections of galled petioles showed various life stages of the EGW (Plate 9). The larva was milky white in colour and 'carrot shaped'. When placed in a drop of water it showed wriggling movements. The pupa was exarate and initially white in colour, with a tinge of green in the abdominal region. Subsequently the pupa showed distinct red colour in the eyes. The eyes were laterally projecting. Later the milky white colour of the pupa gradually changed to brown, the appendages became clearly visible and the red colour of the eyes changed to black .Subsequently , the laterally projecting eyes became prominent with distinct red colour. The male was slender when compared to the females. The females were stout , dark coloured and bigger in size.

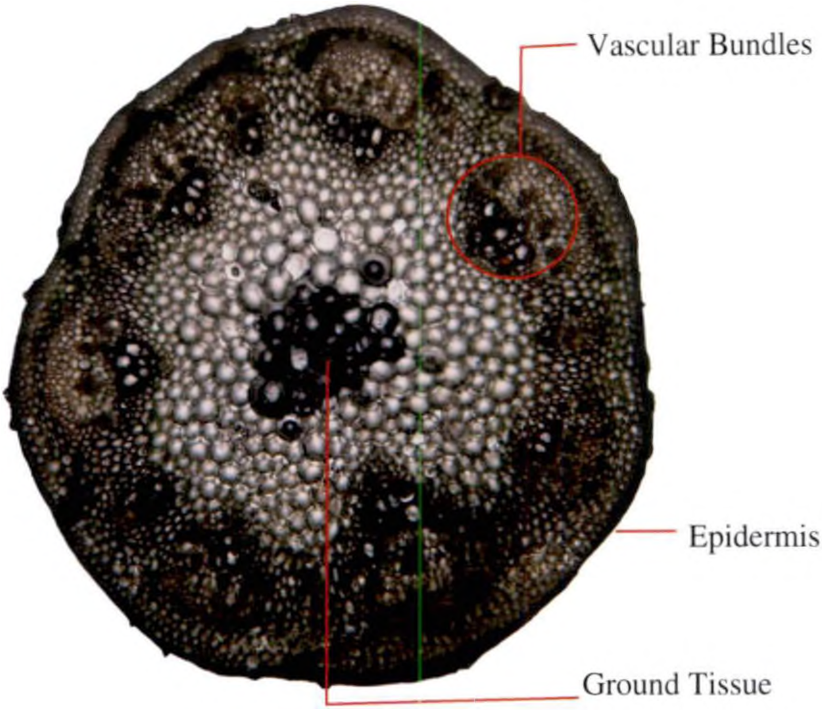


Healthy Erythrina leaf.

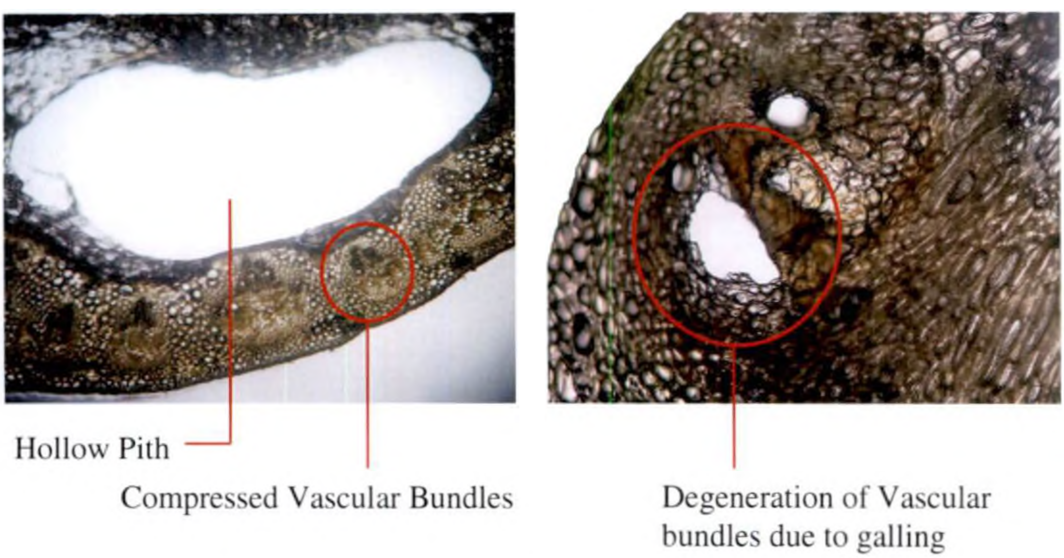


Galled Erythrina leaf

Plate 7. Comparison of longitudinal section of normal and galled *E. stricta* leaf

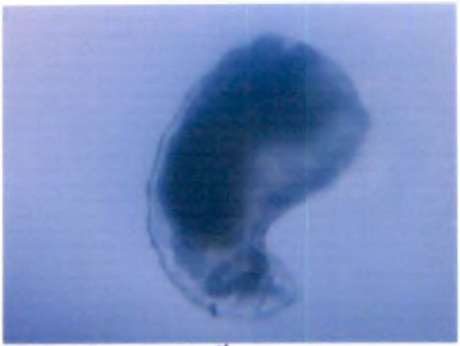


Cross section of healthy petiole



Cross section of galled petioles

Plate 8. Comparison of cross sections of normal and galled *E. stricta* petioles



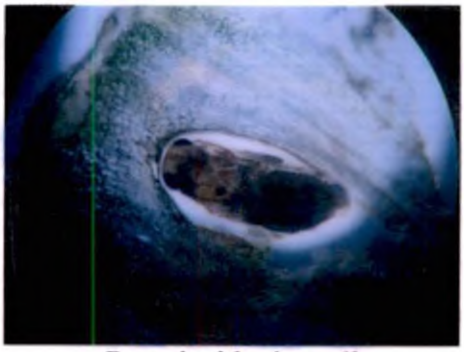
Larvae (1st stage)

Larvae (2nd stage)

Initial stage of Pupa

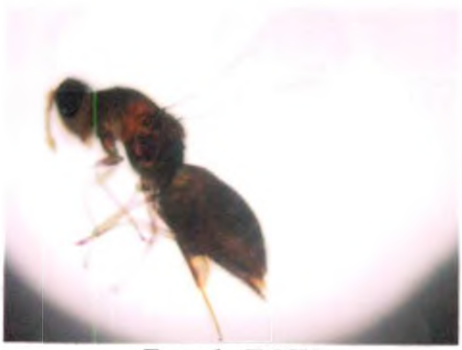
Pupa showing red eyes

Exarate Pupa



Pupa inside the gall

Male EGW



Female EGW

Plate. 9. Life Stages of EGW

4.3.4. Behaviour of Adult EGW

The male EGW was more active and fast moving than the female (Fig. 3). Both the male and female EGW showed jumping (leaping) movements which was more evident in males than in females

4.3.5 Pattern of Regrowth in *E. Stricta*

Data on the percentage of healthy sprouts produced in the four groups is presented in Table 8. Production of healthy sprouts in the four groups did not differ significantly during the 53 weeks of observations. Production of healthy side shoots during the period of observation ranged from 0 to 54.

4.4 MANAGEMENT OF ERYTHRINA GALL WASP

4.4.1 Bioassay

The LC_{50} values show that the male and female EGW (Table 9 and Table 10) had no variation in contact toxicity to the test insecticides. The insecticides *viz*. thiomethoxam, imidacloprid, carbaryl and acephate showed highest toxicity with lowest LC_{50} values -0.000014, 0.0000632, 0.0000792 and 0.0000272 respectively. Contact toxicity was lowest in dry films of dimethoate (0.0243) and diafenthiuron (0.00636).

4.4.2 Systemic and Translaminar Effect of Insecticides

The data on emergence of EGW after the application of treatments is given in Table 11.

The data on emergence of adult population of EGW from sprayed trifoliate leaves in the laboratory showed that the highest control as indicated by lowest number of emergence was in leaves sprayed with triazophos 0.05 per cent (0), followed by imidacloprid 0.002 per cent (1.5), acetamiprid 0.003 per cent (3.5),

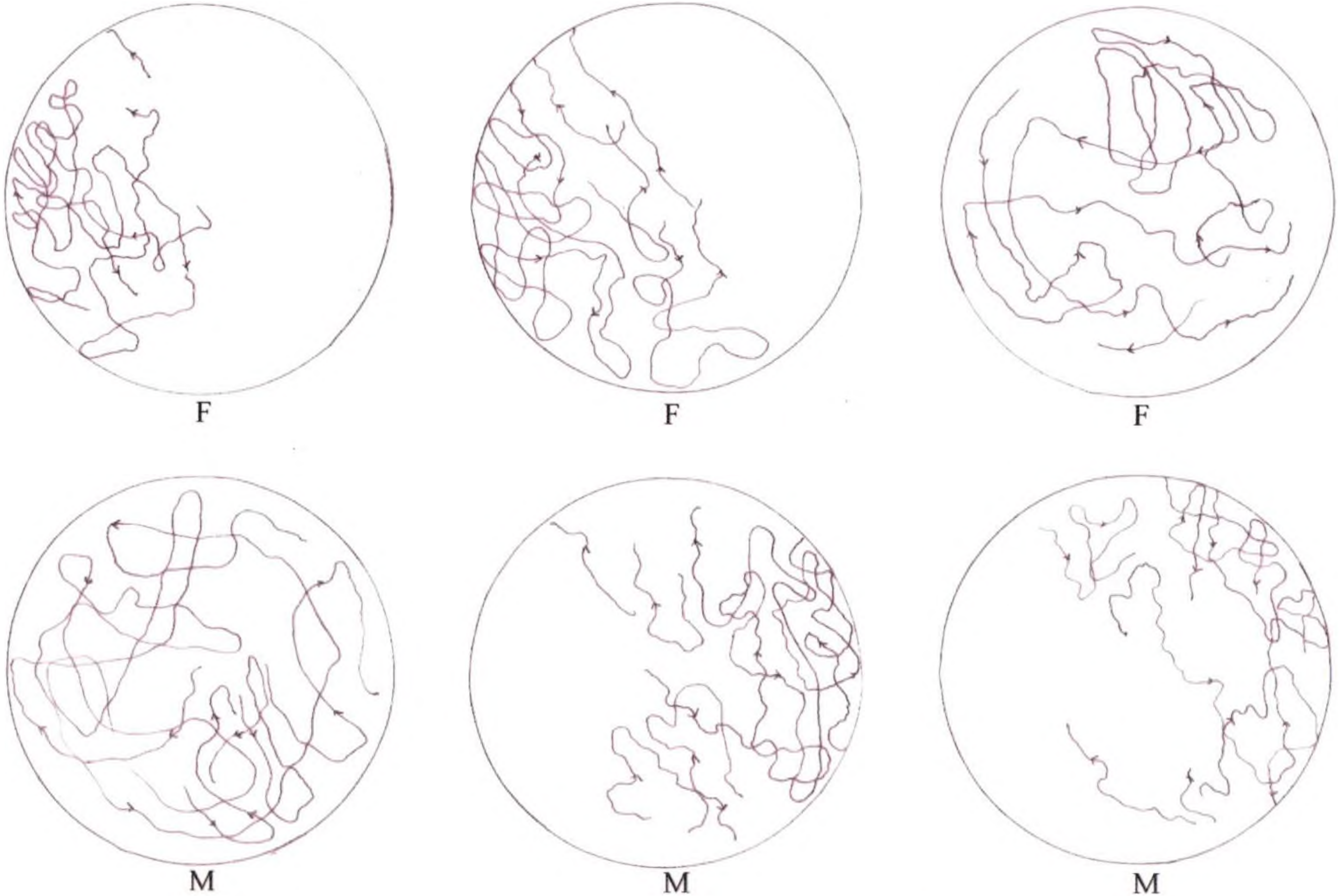


Fig. 3. Movement of female and male EGW in a closed petri plate

Table 8. Percentage of production of healthy sprouts in four groups of E.stricta observed for 53 weeks.

Std Week	Month	Group1 (1 to 3 m)	Group2 (3 to 6 m)	Group 3 (greater than 6 m)	Group 4 (severely pruned)
1	3-Aprl-06	6.698 (14.993)	25.018 (30)	0 (0)	0 (0)
2	4-Aprl-06	6.975 (15.308)	54.555 (47.594)	0 (0)	0 (0)
3	1-May-06	0.874 (5.365)	51.294 (45.723)	6.153 (14.357)	0 (0)
4	2-May-06	0 (0)	3.342 (10.530)	9.446 (17.892)	6.698 (14.993)
5	3-May-06	16.920 (24.279)	0 (0)	3.015 (9.995)	0 (0)
6	4-May-06	37.977 (38.028)	6.698 (14.993)	2.369 (8.851)	5.765 (13.887)
7	5-May-06	25.018 (30)	9.801 (18.236)	17.860 (24.989)	7.837 (16.251)
8	1-Jun-06	0 (0)	11.503 (19.817)	18.599 (25.537)	1.277 (6.487)
9	2-Jun-06	0 (0)	7.501 (15.889)	1.355 (6.683)	12.371 (20.584)
10	3-Jun-06	0 (0)	7.818 (16.230)	0.707 (4.823)	1.038 (5.847)
11	4-Jun-06	0 (0)	1.277 (6.487)	3.194 (10.291)	16.355 (23.845)
12	1-Jul-06	0 (0)	4.150 (11.750)	2.653 (9.371)	2.369 (8.851)
13	2-Jul-06	0 (0)	2.653 (9.371)	1.952 (8.028)	7.837 (16.251)
14	3-Jul-06	0 (0)	3.015 (9.995)	0 (0)	7.374 (15.750)
15	4-Jul-06	0 (0)	1.443 (6.898)	4.353 (12.038)	12.241 (20.471)

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16	1-Aug-06	0 (0)	0 (0)	8.150 (16.581)	1.443 (6.898)
17	2-Aug-06	0 (0)	0 (0)	2.182 (8.492)	4.150 (11.750)
18	3-Aug-06	0 (0)	0 (0)	0.449 (3.844)	0 (0)
19	4-Aug-06	0 (0)	8.472 (16.916)	4.150 (11.750)	0 (0)
20	5-Aug-06	0 (0)	8.472 (16.916)	11.459 (19.778)	0 (0)
21	1-Sep-06	0 (0)	9.802 (18.237)	7.656 (16.056)	0 (0)
22	2-Sep-06	0 (0)	25.018 (30)	10.387 (18.794)	0 (0)
23	3-Sep-06	0 (0)	25.018 (30)	5.213 (13.193)	0 (0)
24	4-Sep-06	0 (0)	11.697 (19.991)	3.236 (10.359)	0 (0)
25	1-Oct-06	0 (0)	25.018 (30)	1.355 (6.683)	0 (0)
26	2-Oct-06	0 (0)	25.018 (30)	1.747 (7.592)	0 (0)
27	3-Oct-06	0 (0)	25.018 (30)	0 (0)	0 (0)
28	4-Oct-06	0 (0)	25.018 (30)	4.150 (11.750)	0 (0)
29	5-Oct-06	0 (0)	25.018 (30)	0 (0)	0 (0)
30	1-Nov-06	0 (0)	25.018 (30)	0 (0)	0 (0)
31	2-Nov-06	0 (0)	25.018 (30)	0 (0)	2.369 (8.851)
32	3-Nov-06	0 (0)	25.018 (30)	0 (0)	1.952 (8.028)
33	4-Nov-06	0 (0)	25.018 (30)	0 (0)	0 (0)
34	1-De06	0 (0)	25.018 (30)	0 (0)	4.150 (11.750)

35	2-Dec-06	0 (0)	25.018 (30)	0 (0)	4.150 (11.750)
36	3-Dec-06	0 (0)	25.018 (30)	0 (0)	4.150 (11.750)
37	4-Dec-06	0 (0)	25.018 (30)	0 (0)	0 (0)
38	1-Jan-07	0 (0)	25.018 (30)	0 (0)	0 (0)
39	2-Jan-07	0 (0)	25.018 (30)	0 (0)	0 (0)
40	3-Jan-07	0 (0)	25.018 (30)	0 (0)	0 (0)
41	4-Jan-07	0 (0)	25.018 (30)	0 (0)	0 (0)
42	5-Jan-07	0 (0)	25.018 (30)	0 (0)	0 (0)
43	1-Feb-07	0 (0)	25.018 (30)	0 (0)	0 (0)
44	2-Feb-07	0 (0)	25.018 (30)	0 (0)	0 (0)
45	3-Feb-07	0 (0)	25.018 (30)	0 (0)	0 (0)
46	4-Feb-07	0 (0)	25.018 (30)	4.150 (11.750)	25.018 (30)
47	1-Mar-07	0 (0)	25.018 (30)	4.150 (11.750)	0 (0)
48	2-Mar-07	0 (0)	25.018 (30)	25.018 (30)	0 (0)
49	3-Mar-07	0 (0)	25.018 (30)	25.018 (30)	0 (0)
50	4-Mar-07	0 (0)	25.018 (30)	25.018 (30)	0 (0)
51	1-Aprl-07	0 (0)	25.018 (30)	16.355 (23.845)	0 (0)
52	2-Aprl-07	0 (0)	25.018 (30)	12.407 (20616)	0 (0)
53	3-Aprl-07	0 (0)	25.018 (30)	0.874 (5.365)	0 (0)
CD (0.05)		-	-	-	-

Figures in the parenthesis are after angular transformation

Table 9. Toxicity of different insecticides against female *Q.erythrinae* when exposed to dry film

Sl No.	Insecticide	Regression Equation	LC_{50}
1	acephate	$46.64 \times e^{2558.72X}$	2.72×10^{-5}
2	dimethoate	$8.93 \times e^{70.79X}$	2.43×10^{-2}
3	triazophos	$37.64 \times e^{774.2X}$	3.67×10^{-4}
4	chlorpyriphos	$35.64 \times e^{2924.74X}$	1.16×10^{-4}
5	lamdacyhalothrin	$18.11 \times e^{1404.63X}$	7.23×10^{-4}
6	imidacloprid	$43.77 \times e^{2106.77X}$	6.32×10^{-5}
7	carbaryl	$27.43 \times e^{7585.61X}$	7.92×10^{-5}
8	abamectin	$31.79 \times e^{1354.89X}$	3.34×10^{-4}
9	lufenuron	$24.70 \times e^{1398.34X}$	5.04×10^{-4}
10	diafenthiuron	$17.32 \times e^{166.65X}$	6.36×10^{-3}
11	acetamiprid	$35.77 \times e^{740.62X}$	4.52×10^{-4}
12	thiomethoxam	$53.65 \times e^{5182.26X}$	-1.4×10^{-5}

Table 10. Toxicity of different insecticides against male *Q.erythrinae* when exposed to dry film

Sl No.	Insecticide	Regression Equation	LC_{50}
1	acephate	$46.64 \times e^{2558.72X}$	2.72×10^{-5}
2	dimethoate	$8.93 \times e^{70.79X}$	2.43×10^{-2}
3	triazophos	$37.64 \times e^{774.2X}$	3.67×10^{-4}
4	chlorpyriphos	$35.64 \times e^{2924.74X}$	1.16×10^{-4}
5	lamdacyhalothrin	$18.11 \times e^{1404.63X}$	7.23×10^{-4}
6	imidacloprid	$43.77 \times e^{2106.77X}$	6.32×10^{-5}
7	carbaryl	$27.43 \times e^{7585.61X}$	7.92×10^{-5}
8	abamectin	$31.79 \times e^{1354.89X}$	3.34×10^{-4}
9	lufenuron	$24.70 \times e^{1398.34X}$	5.04×10^{-4}
10	diafenthiuron	$17.32 \times e^{166.65X}$	6.36×10^{-3}
11	acetamiprid	$35.77 \times e^{740.62X}$	4.52×10^{-4}
12	thiomethoxam	$53.65 \times e^{5182.26X}$	-1.4×10^{-5}

thiomethoxam 0.002 per cent (7.25) and dimethoate 0.05 per cent (58.25) and there was no significant difference between these treatments making all five insecticides equally effective with respect to systemic and translaminar effect. However acephate did not show significant difference from the control as indicated by emergence of 113.75 and 146.75 gall wasps respectively.

4.4.3 Efficacy of Plant Based Insecticides

The results of the field experiment on the effect of plant based insecticides for the protection of newly formed shoots are presented in Table 12. The data on number of days between the spraying and appearance of galls showed significant variation among treatments. Longest period of protection of new shoots from gall infestation was obtained by spraying 2 per cent neem oil –garlic- soap emulsion which was on par with the treatment of 2 per cent neem oil emulsion, the mean number of days between spraying and appearance of galls being 29.33 and 26 respectively. This was followed by spraying 2 per cent illuppai oil which gave 22.3 days of protection and there was no significant difference among the three treatments. Garlic extract 2 per cent emulsified with soap was the next in ranking which kept the new shoots without any apparent symptom of gall infestation up to 20 days. But it was inferior to spraying with neem oil- garlic, neem oil alone or pongamia oil. Mean number of days without any visible symptom of gall infestation in the spraying of the side shoot with 2 per cent castor oil (10 days), 2 per cent karingotti oil (13 days), 2 per cent pongamia oil(16 days), azadiractin 0.002 per cent (19 days) and garlic extract 2 per cent (20 days) did not differ significantly protect the plants when compared to the control plot (14 days).

4.4.4 Field Experiment

The percentage of healthy sprouts produced at different intervals after application of selected botanical and chemical insecticides on EGW infested Erythrina trees trailed with pepper vines is presented in Table 13.

Table 11. Effect of spraying chemical insecticides with systemic / translaminar. action on population of EGW emerged from galled trifoliate leaves of *E.Stricta*

Treatments	Emergence number per leaflet
Acephate 0.05%	113.75
Dimethoate 0.05%	58.25
Triazophos 0.05%	0
Imidacloprid 0.002%	1.5
Acetamiprid 0.003%	3.5
Thiomethoxam 0.002%	7.25
control	146.75
CD (0.05)	59.55

Table 12. Effect of spraying plant based insecticides on the extent of protection of newly formed side shoots of *E.stricta.*

Treatments	Number of days between spraying and appearance of galls
Neem oil 2%	26
Neem oil garlic 2%	29.33
Garlic extract 2%	20
Azadiractian 0.002%	19
Castor oil 2%	10
Karingotti oil 2%	13
Illuppai oil 2%	22.33
Pongamia oil 2%	16
Control	14
CD (0.05)	7.050

Table 13. Percentage of healthy side shoots observed at different intervals after spraying insecticides.

Treatment	ATS	2WAS	4WAS	6WAS	8WAS
acephate (0.05%) + carbendazim	93.33 (74.99)	98.97 (83.14)	97.64 (81.14)	99.99 (90)	44.36 (41.74)
acephate (0.05%)	99.99 (90)	98.57 (83.09)	98.34 (82.58)	75.04 (60)	75.04 (60)
dimethoate (0.05%)+ carbendazim	75.03 (60)	75.04 (60)	99.99 (90)	99.99 (90)	99.99 (90)
dimethoate (0.05%)	83.23 (65.80)	94.21 (76.04)	80.33 (63.65)	99.99 (90)	99.19 (84.80)
imidaclorprid (0.002%)+ carbendazim	97.34 (80.59)	99.99 (90)	99.99 (90)	99.99 (90)	99.99 (90)
imidaclorprid (0.002%)	96.51 (79.21)	92.58 (74.16)	94.90 (76.92)	99.99 (90)	75.04 (60)
lamdacyhalothrin (0.05%)	96.32 (78.92)	96.33 (78.92)	65.53 (54.03)	18.09 (25.16)	7.003 (15.34)
chlorpyriphos (0.05%)	98.96 (84.13)	94.004 (75.79)	84.71 (66.95)	53.37 (46.92)	25.02 (30)
carbaryl (0.1%)	91.56 (73.08)	99.05 (84.37)	99.99 (90)	99.99 (90)	99.99 (90)
triozophos (0.05%)	84.63 (66.89)	99.99 (90)	99.99 (90)	25.02 (30)	25.02 (30)
neem oil-garlic (2%)	83.91 (66.32)	98.35 (82.58)	99.99 (90)	99.99 (90)	99.99 (90)
neem oil (2%)	73.72 (59.14)	99.99 (90)	99.99 (90)	99.99 (90)	99.99 (90)
CD (0.05)	-	-	18.16	43.27	55.74

Figures in the parenthesis are after angular transformation

ATS=At the time of spraying
2WAS= two weeks after spraying
4WAS= four weeks after spraying
6WAS= six weeks after spraying
8WAS= eight weeks after spraying

Two weeks after spraying

None of the treatments showed any significant effect on the production of healthy side shoots in the *E.stricta* standards

Four weeks after spraying

All the treatments gave significantly superior protection to the newly produced sideshoots. Dimethoate 0.05 per cent + carbendazim 0.2 per cent, lamdacyhalothrin 0.05 per cent + carbendazim 0.2 per cent, carbaryl 0.1 per cent, triazophos 0.05 per cent, neem oil-garlic 2 per cent and neem oil 2 per cent were significantly superior to the other treatments as evident from the same value (99.99) for percentage production of side shoots in all the treatments. This was followed by acephate 0.05 per cent (98.34), acephate 0.05 per cent + carbendazim 0.2 per cent (97.64) and imida cloprid 0.002 per cent (94.90)

Healthy side shoot production was the lowest in trees sprayed with lamda cyhalothrin 0.05 per cent. Spraying dimethoate 0.05 per cent (80.33) and chlorpyrifos 0.05 per cent (84.71) were on par with lamdacyhalothrin 0.05 per cent (65.53).

Six weeks after spraying

At six weeks after spraying, all treatments gave significantly superior results in the production of healthy side shoots. High level of side shoot production could be recorded in trees sprayed with acephate 0.05 per cent + carbendazim 0.2 per cent, dimethoate 0.05 per cent + carbendazim 0.2 per cent, dimethoate 0.05 per cent, lamdacyhalothrin 0.05 per cent, imidacloprid 0.002 per cent + carbendazim 0.2 per cent, carbaryl 0.1 per cent, imidacloprid 0.002 per cent ,neem oil-garlic 2 per cent and neem oil 2 per cent (99.99) in all the treatments.

The lowest percentage of sprout production was observed in standards sprayed with triazophos 0.05 per cent (25.03) and lamdachyhalothrin 0.05 per cent (18.09).

Eight weeks after spraying

Even after eight weeks of spraying a similar trend was noticed in the sprout production in dimethoate 0.05 per cent + carbendazim 0.2 per cent, imidacloprid 0.002 per cent + carbendazim 0.2 per cent, carbaryl 0.1 per cent, neem oil-garlic 2 per cent, neem oil 2 per cent (99.99) and dimethoate 0.05 per cent (99.19). This was followed by acephate 0.05 per cent (75.04) and acephate 0.05 per cent + carbendazim 0.2 per cent (44.36).

The lowest number of side shoots was observed in lamdacyhalothrin 0.05 per cent (7.003), which were on par with chlorpyrifos 0.05 per cent and triazophos 0.05 per cent (25.02).

An overall analysis of the data showed that the application of dimethoate (0.05 per cent) alone or in combination with carbendazim (0.2 per cent), carbaryl (0.1 per cent), neem oil (2 per cent), neem oil-garlic (2 per cent) and imidacloprid (0.002 per cent) + carbendazim (0.2 per cent) effectively protected the new side shoots up to eight weeks after spraying.

4.5 TERMINAL RESIDUES IN DRY PEPPER

The residues present in dry pepper berries collected 1day after spraying (DAS), 7DAS, and at harvest from pepper plants trailed on the insecticide treated Erythrina trees are presented in Table 13.

The highest insecticide deposit was detected in pepper berries collected one day after spraying from the trees sprayed with lamdacyhalothrin 0.05percent (6.66ppm). This was followed by triazophos 0.05percent (2.19ppm). Residues in pepper collected from other treatments *viz.* acephate 0.05 per cent, dimethoate 0.05 per cent and chlorpyriphos 0.05 per cent remained low, the levels being 0.13ppm, 0.07ppm and 0.19 ppm respectively.

At seven days after spraying, deposits were detected in berries treated with lamdacyhalothrin 0.05 per cent, chlorpyriphos 0.05 per cent and triazophos 0.05 per cent. Among the three, residues of lamdacyhalothrin 0.05 per cent was the

Table 14. Residues of selected insecticides in dry pepper at different intervals after application as foliar spray on *Erythrina stricta* standards.

Treatments	Mean residues in ppm in dry pepper berries collected		
	1 DAS	7DAS	At harvest
Triozophos	2.19	1.48	1.16
Acephate	0.13	BDL	BDL
Dimethoate	0.07	BDL	BDL
Chlorpyriphos	0.19	0.09	0.07
Lamda cyhalothrin	6.659	3.917	1.387
Control	BDL	BDL	BDL

BDL -Below detectible limit
1 DAS -One day after spraying
7 DAS -Seven day after spraying

highest (3.917 ppm) and this was followed by those of triazophos 0.05 per cent and chlorpyriphos 0.05 per cent (1.48ppm and 0.09ppm). Residues in pepper berries treated with acephate 0.05 per cent and dimethoate 0.05 per cent were below detectable levels.

At the time of harvest the residual deposits was low in pepper berries collected from trees sprayed with lamdacyhalothrin 0.05 per cent (1.387ppm), triazophos 0.05 per cent (1.16ppm) and chlorpyriphos 0.05 per cent (0.07ppm). The berries from treatments acephate 0.05 per cent and dimethoate 0.05 per cent were below detectable levels.

DISCUSSION

5. DISCUSSION

Many insect groups, an estimated 13000 species, induce plant gall-structures composed of plant tissue within which the insect feeds, which are distinguished from other insect generated shelters such as rolled leaves or leaf mines by the fact that they involve active differentiation and growth of plant tissues (Stone et al., 2003).

Among the micro hymenopteran gallers, *Q.erythrinae* is reported to damage *Erythrina* species popularly known as coral trees, leading to severe defoliation and death of trees in the Indian sub continent (Faizal et al., 2006). This invasive and exotic new species of gall wasp, having a highly specific host range of *Erythrina* species, spread rapidly to the entire pepper growing tracts in Trivandrum, Pathanamthitta, Kottayam and Ernakulam districts where the trees are cultivated as trellises (standards) for pepper vines.

Of late, it has made its appearance in a very devastating level in the high ranges of Idukki and Wyanad districts also where pepper is cultivated extensively using *Erythrina* trees as the major live standards. Farmers have reported seasonal changes in the severity of gall infestation on *Erythrina* trees and in some places the severely infested standards fell down carrying the pepper vines entangled around the fallen trunk. On examination of the fallen trees and the trees about to fall, it was found that the galled plant parts succumb to secondary infection of a fungus that caused severe rotting of bark region which resulted in the toppling of the trees. The infestation caused heavy loss to the pepper cultivators in Kerala, and the matter was taken up for discussion in the Kerala legislative assembly.

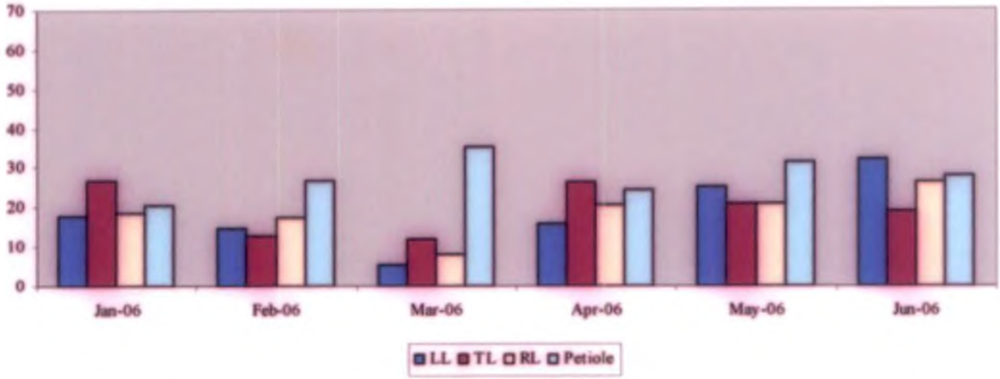
Considering the importance of the pest, a study was taken up to monitor the population dynamics of gall wasp and to suggest suitable management practices. Information on population fluctuation of any insect pest is very critical for developing long-term management strategy. Adult emergence from infested leaves and petioles was studied to assess population dynamics. Observations on temporal pattern of adult emergence varied among sub samples *viz* trifoliate leaflets and petioles. In general, petiole specimens yielded significantly higher number of gall wasps than abscised leaflets in the major period of study (Fig. 4). However, emergence from individual leaflets in certain months exceeded the population from petioles. Maximum number of adult wasps emerged from a single petiole came up to 27 whereas the maximum emergence from left lateral, terminal leaflet and right lateral were up to 27, 31 and 12 respectively.

The pattern of emergence of total (male and female) population from leaflets and petioles, continuously for 78 weeks did not exhibit any month-war trend for peak population. However, it followed a repetition of peak emergence at an interval of about 6-8 weeks, as evident from the data recorded during the weeks 6, 14, 19, 29, 31, and then 46, 52-53, 59-61, 67 and 75, without any major peaks during the weeks 34 (August 2006) to 44 (October 2006) (Fig. 5). It may be assumed that an interval of six to eight weeks is required between successive generations under field conditions.

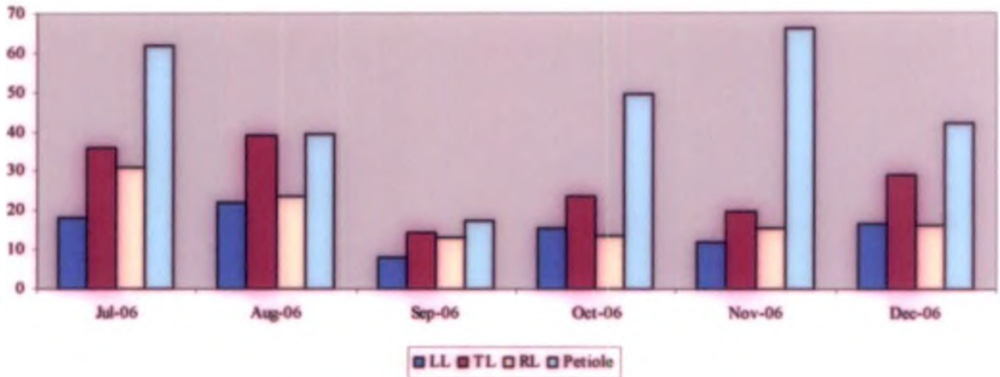
Another interesting observation made from the field study was the existence of a six monthly repeating trend for sequential phases of foliage production, gall inducement, drying and abscission of galled parts and complete cessation of growth in *E.stricta* (Fig. 2). Similar findings were made by Raman and Withers (2003) who observed a repeating trend of defoliation and die back, of heavily infested *Eucalyptus botryoides* in New Zealand produced by *Ophelimus eucalypi* (Hymenoptera: Eulopidae). Thus during the period of 18 months of field observation, three damage cycles could be observed *viz*. January-June 2006, July-Dec 2006 and January-June 2007.

When month wise data on population emergence of EGW was re-examined with reference to the damage cycles and phenology of foliage production, emergence of *Q. erythrinae* showed a definite trend of gradual

January 06 to June 06.



July 06 to December 06.



January 07 to June 07.

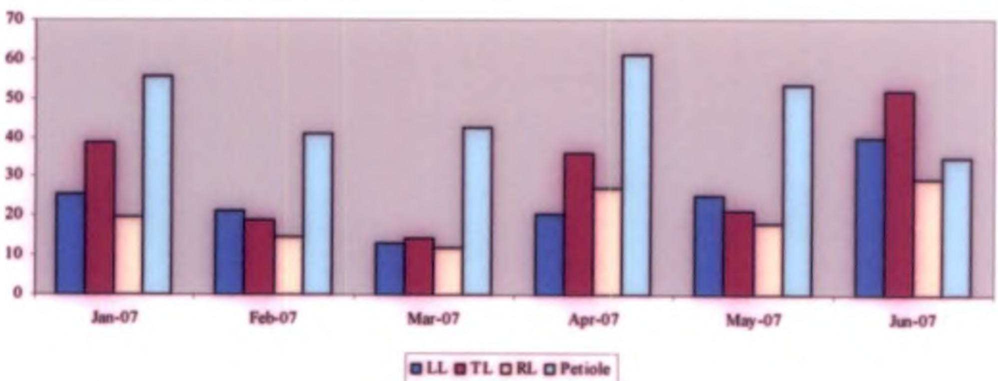


Fig. 4. Population of EGW (male and female) emerged from three leaflets and petiole samples collected during three , six monthly damage cycles

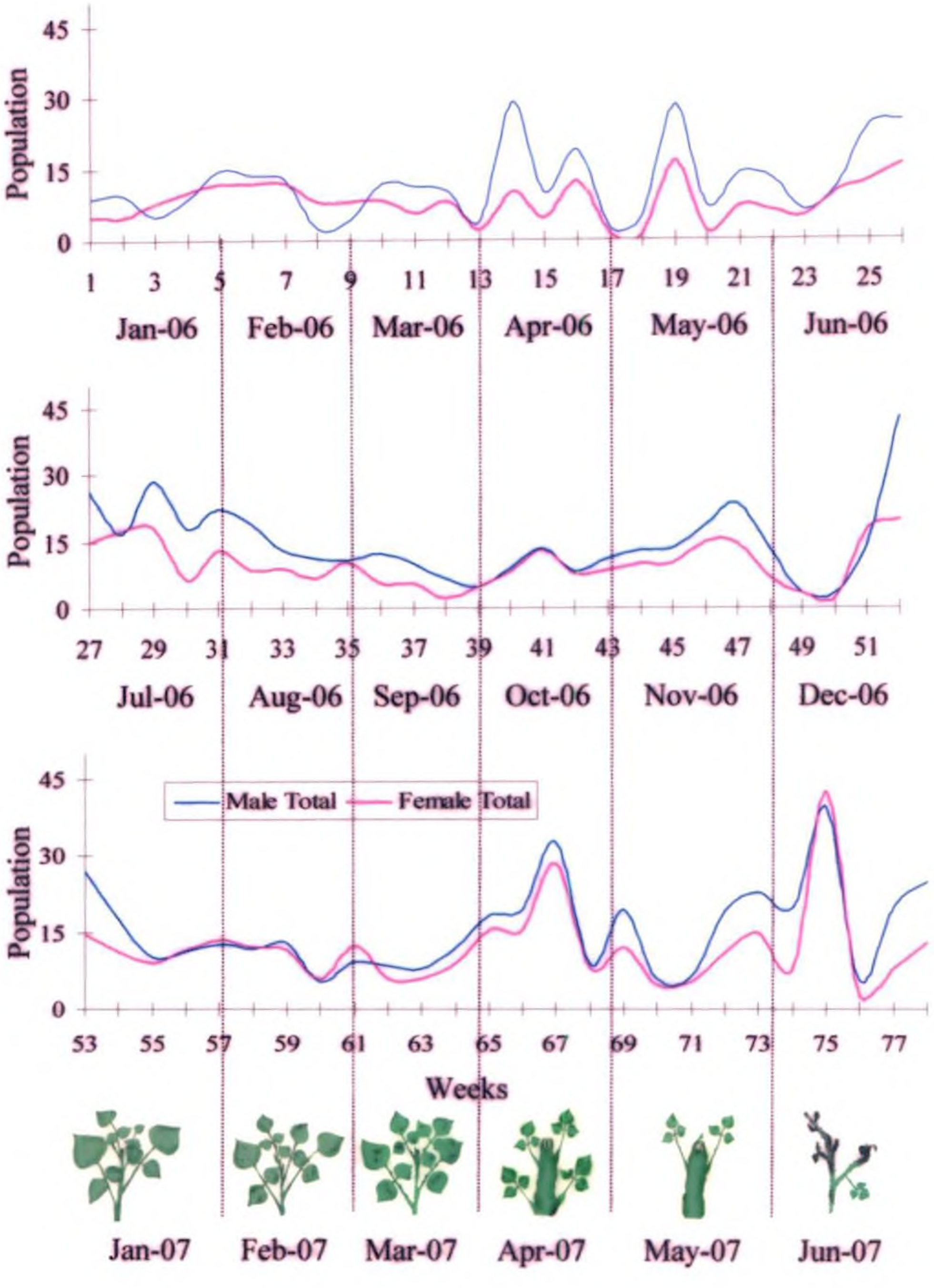


Fig. 5. Total male and female EGW population emerged from the subsamples during 78 weeks (18 months)

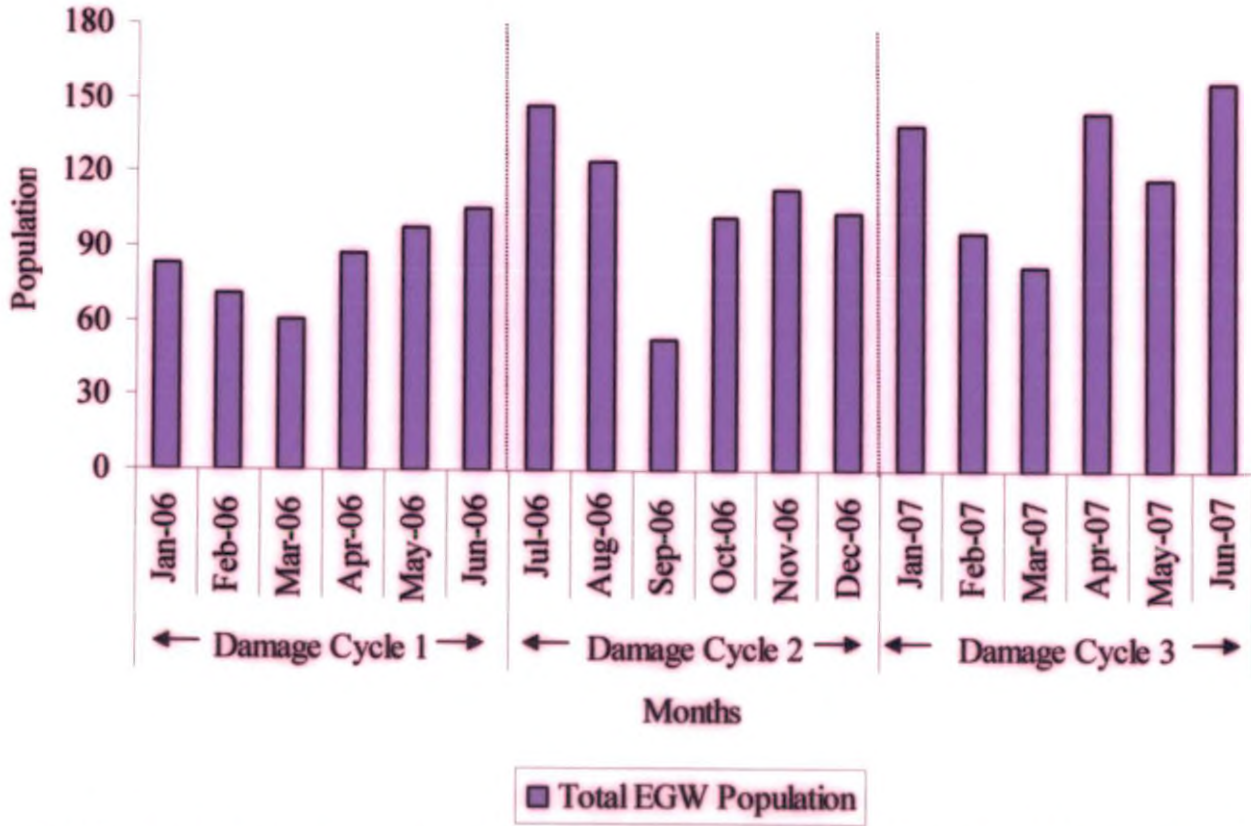


Fig. 6. Total population of EGW emerged from the samples (leaflet and petiole) collected during three damage cycle (January 2006 to June 2007)

increase of population towards the end portion of each six monthly damage cycle(Fig. 4 and Fig. 6). This trend broadly coincided with the degree of galling and with the rising populations towards the last stages of the cycle when the trees stop complete growth process for a short period and present an "apparently dead looking and foliage less stage". The results indicated that March and September are ideal periods for insecticidal interventions which coincide with peak foliage production ,just before peak population build up.

The male population emerged from leaflets was found positively correlated with minimum temperature during 14 days, 21 days and 28 days before emergence, where as male and female population emerged from petioles were positively correlated with rainfall during the week 28 days before emergence. Contradictory results have been reported by Bhatt and co-workers (2004) who observed a positive correlation with minimum RH and negative correlation with minimum temperature and population of Mustard Sawfly *Athalia lugens* (Hymenoptera: Tenthredinae).

The variation in biomass and number of galls produced by EGW in samples are detailed in paragraph 4.1.1.6 and 4.1.1.7 under results (Table 3.) The mean increase in biomass due to EGW infestation was maximum in the left lateral (2.48 g/leaflet) followed by petiole (2.01g) and right lateral (1.61g). Similarly the maximum number of galls were observed in left lateral leaf (30.40) followed by right lateral (21.12) and terminal leaflet (19.64). The mean intensity score of the petioles was found to be 3.58 /petiole. The male, female and total pest population showed positive correlation with weight of the terminal leaflets, weight of the petioles and also with mean intensity score of the petioles. This indicated the scope of using the weight of the petiole or terminal leaflet samples as an indirect observation for assessment of pest population.

The study of biometric observation of the normal and galled petioles showed that the weight of the left lateral, terminal leaflet and the right lateral increased two fold on account of EGW infestation. The weight of the petioles also increased to the time of two fold. The girth of the petiole increased greater than two fold from that of the normal. Faizal and co- workers (2006) reported that the mean thickness of galled petioles was 3.1 times more than that of normal. In the present study it was also observed that the length of the petioles was reduced to one third from that of normal, due to abnormal thickening and stunting (Plate 5c).

Emergence of the adults from petiole samples coming under different damage scores showed that the maximum number of pest emergence was from the score '9' (37. 3 ± 14.29 wasps/petiole) and the minimum number of emergence was from the score '1' (7.6 ± 1.90 wasps/petiole). The girth of the petiole was 4.03 ± 0.17 cm and the weight of the petiole was 3.64 ± 1.09 g in samples under score '9'. Weight and girth of uninfested petiole samples was 1.37 ± 0.30 and girth 1.14 ± 0.21 cm respectively.

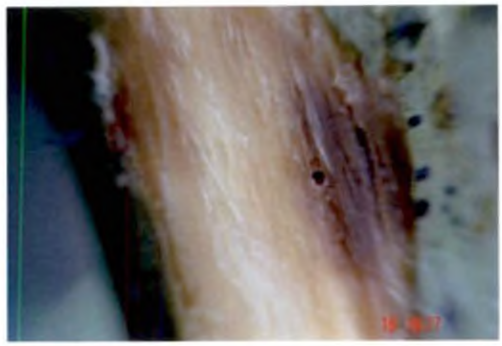
The results given under paragraph 4.3.3 showed definite changes in the cells of EGW infested plant parts. Histological studies of the galled plant parts showed increase in the size of the cell or losing of the cell shape degeneration of the palisade tissue in leaf alteration in palisade tissue, compressed vascular bundles in the petioles, degeneration of ground tissue leading to the formation of hollow pith. Closely packed cell lining in the gall cavity which is filled with nutritive tissue devoid of chlorophyll. This study was carried out for the first time in EGW infested plants.

The pattern of re-growth after defoliation and cessation of growth in *E.stricta* was studied after categorizing the trees into 4 groups based on height and branching pattern. The results presented in 4.3 and Table 8 did not show any significant variation among the four groups of trees observed. This showed that the architecture or height of the tree did not influence the pattern of re-growth after defoliation caused by EGW infestation.

Observations were also taken for *E.stricta* trees severely infested by EGW and secondary infection by fungal rot. Severely infested trees when observed for development of secondary infection by fungi. Typical symptoms of advance stage of bark rot could be identified (Plate 10). The advanced stage of rotting results in shredding of the bark. Subsequently the shredded bark peel off from the plant and fall to its base along with pepper vines. These stages were documented with a view to understand the disease development to take early action to suppress secondary infection and save the trees. Data presented in Table 15 showed that cent per cent of the young trees under group 1 (1-3 m height) died due to secondary infection by fifth month commencement of the observational trial. However, up to 34 per cent of trees coming under group 2 (3-6 m height), group 3 (> 6 m height) and group 4 (severely pruned trees) did not succumb to death until 12 months after commencement of the trial. This indicated that newly planted cuttings and young trees of *E.stricta* should be given more care and should be properly protected from secondary infection by fungus.

In the experiment to evaluate a set of twelve selected chemical and bio rational insecticides for their contact toxicity to male and female *Q. erythrinae*, the LC_{50} values were found to be the same for male and female gall wasps indicating the same level of dose- response to both sexes irrespective of their size differences are detailed in paragraph 4.4.1 under results (Table 9 and Table 10). Regression analysis of the data on mortality of EGW and concentrations of dry films revealed exponential trend for dose response and the LC_{50} values worked out based on regression equations showed very high toxicity for almost all insecticides tested as evident from their very low LC_{50} values ranging from 0.00006 to 0.024 per cent. Highest level of contact toxicity was shown by thiomethoxam at 0.000125 per cent concentration followed by imidacloprid at 0.0005 per cent. The mortality data also showed that the lowest concentrations of chemical and bio rational insecticides required to kill cent per cent mortality of the pest population also varied very much. Among the six chemical insecticides

Powdery mass of plant tissue shooting out from the damaged bark



Pore on the bark from which the powdery mass appear

Shredding of the bark upon secondary fungal infection

Fallen shreds at the base of the plant due to advance rotting of the bark

Fallen pepper vines at the base of the plant along with shredded bark

Barren plant after shredding of the complete bark

Plate. 10. Symptoms of secondary infection of *E.stricta* trees

Table 15. Death of *E. stricta* trees of four age groups severely infested by EGW and secondary infection by fungus.

Month	Percentage of dead trees in different categories			
	Group 1 (1-3 m height)	Group 2 (3-6 m height)	Group 3 (> 6 m height)	Group 4 (severely pruned trees)
April 2006	0	0	33%	33%
May 2006	0	0	6.6%	26.4 %
June 2006	33 %	8.25 %	0	33 %
July 2006	83 %	33 %	0	33 %
August 2006	100 %	39.6 %	0	66 %
September 2006	100 %	66 %	0	66 %
October 2006	100 %	66 %	13.2 %	66 %
November 2006	100 %	66 %	33 %	66 %
December 2006	100 %	66 %	66 %	66 %
January 2007	100 %	66 %	66 %	66 %
February 2007	100 %	66 %	66 %	83 %
March 2007	100 %	83 %	66 %	100 %
April 2007	100 %	100 %	66 %	100 %

tested, lowest concentration required to kill cent per cent of EGW population tested was 0.0000792 per cent (carbaryl) which was followed by 0.0000272 per cent (acephate), 0.000116 per cent (chlorpyriphos), 0.0015625 (triazophos),0.000723 per cent (lamda cyhalothrin) and 0.02 per cent (dimethoate). Similar values of minimum concentration of dry film made from the bio-rationals tested required to kill cent per cent of EGW population were 0.000125 (thiomethoxam), 0.0005 per cent (imidacloprid), 0.001 per cent (abamectin), 0.0015 per cent (acetamiprid) and 0.01 per cent (diafenthiuron). The results of this experiment clearly demonstrated the scope of using thiomethoxam, imidacloprid, carbaryl or acephate for management of EGW.

Systemic/translaminar effect of insecticides to EGW was assessed in another experiment by observing emergence of the insect from exised galled leaves sprayed with the systemic insecticides. Results in Table 11. showed cent per cent mortality of EGW in the treatment triazophos at 0.05 per cent, acetamiprid 0.003 per cent and thiomethoxam 0.002 per cent with negligible emergence of 1.5, 3.5, and 7.5 insects /trifoliate leaf while a mean number of 146.8 gall wasps emerged from untreated leaves. Considering the results from two experiments to evaluate contact and systemic effects, the bio-rationals imidacloprid and thiomethoxam could be identified as the most effective bio-rational and triazophos, the most effective chemical insecticide. Results of this experiment are in conformity with the finding of Eileen and Daniel (2000) who reported a significant mortality of gall wasp *Callirhytis cornigera* and parasitoids, in the galls after canopy sprays with abamectin, dimethoate and imidacloprid. However, such a detailed information on laboratory evaluation of contact and systemic/ translaminar effect of insecticides was not available from the reports of earlier workers who made attempts to evaluate insecticide for management of EGW.

None of the previous workers made any attempt to screen plant based insecticides for the control of EGW. In Kerala many pepper growers are taking steps to shift to production of organic pepper. In this context, the field evaluation of botanical insecticides was of paramount importance.

Among the eight botanicals evaluated in the field to study the extent of protection by spraying to fresh side shoots as detailed in paragraph 4.4.3 under results (Table 12), neem oil garlic 2 per cent proved as the best treatment imparting protection of newly formed side shoots up to 29.33 days after spraying. This was followed by neem oil 2 per cent and garlic 2 per cent, the extent of protection of side shoots being 26 and 20 days respectively.

As the last part of the study, a field experiment was conducted in a pepper field at bearing stage to evaluate insecticides selected from the laboratory experiments. Three insecticides were used in combination with carbendazim, a proven systemic fungicide for rot diseases in plantation crops. The effectiveness of the treatment could be evident only from fourth week after spraying in terms of production of healthy sprouts (Table 13).

An overall analysis of the observations in field experiment under Table 13. recorded on fourth, sixth and eighth week after spraying showed that the application of dimethoate 0.05 per cent or imidacloprid 0.002 per cent in combination with carbendazim 0.2 per cent, carbaryl 0.1 per cent, neem oil 2 per cent or neem oil garlic 2 per cent offered maximum protection of newly formed sprouts. The treatment triazophos which was found as the best in the laboratory experiment offered protection only up to four weeks after spraying while imidacloprid and dimethoate protected new growths up to eight weeks after spraying.

The two botanical insecticides *viz.* neem oil 2 per cent and neem oil garlic emulsion 2 per cent deserve special mention in the context of IPM in pepper trailing on erythrina standards, considering their significance in organic pepper production. If at all a chemical / bio- rational insecticide is to be used for control of EGW, due consideration should be given to the choice of dimethoate which is recommended in pepper and is proved effective in combined application with carbendazim, leaving no detectable residues at harvest. However, residue analysis in pepper berries could not be made in the treatments done using imidacloprid or carbaryl due to the lack of high performance liquid chromatograph required for their determination.

In the light of the findings obtained from a series of laboratory and field evaluations, spraying erythrina standards with dimethoate 0.05 per cent + carbendazim 0.2 per cent, imidacloprid 0.002 percent + carbendazim 0.2 per cent, carbaryl 0.2 per cent ,neem oil 2 per cent or neem oil garlic 2 per cent may be recommended for management of EGW infestation. However, from field experience, it may also be emphasized that the spraying on erythrina trees should be done under strict supervision, using experienced labour and perfectly maintained rocker sprayers to achieve the expected level of control. Spraying should be synchronized with actively growing stage of the foliage, just after the commencement of gall formation on foliage.

SUMMARY

6. SUMMARY

The present study entitled "Population dynamics and management of Erythrina gall wasp, *Quadrastichus erythrinae* Kim." was conducted from January 2006 to June 2007 in the Instructional farm, College of Agriculture, Vellayani. The main objectives were to study the population dynamics and the extent of damage and to evolve a management strategy against the pest.

The wasp population was present in the field through out the period of study. The population of the gall wasp was maximum during the months of July2006 (147.17), January 2007(139.5) and June2007 (147.17). Among the sub samples, the highest emergence of EGW was from the petioles (9.18) followed by the terminal leaflets (5.90). The highest number of galls was observed in the left lateral (30.40), followed by right lateral (21.12). Similarly, the maximum biomass of galled tissue was produced in the left lateral (2.48g) followed by petiole (2.01g).

The emergence of male EGW was significantly higher than the emergence of females. During the period of eighteen months of field study, a trend in the phenology of production of sprouts, active foliage growth, galling and complete defoliation in the *E.stricta* trees was noticed. The cycle (trend) lasted for a period of 5-6 months, with a stage of active sprouting, foliage production, galling, peak defoliation and final 'dead like' or 'leafless stage' of the trees at the end of the cycle. The population of EGW was at the maximum in the beginning and towards the end of each cycle.

The insect host interaction studies showed that galls when formed on tender leaves fail to attain the normal shape and size and the thickness of the leaf lamina increased. The galls occur singly and also in groups in leaves. When galls

are found on petiole, they become swollen and curved losing their initial appearance. The larva feeds within the gall cavity filled with nutritive tissue and emerge as winged adults cutting exit holes. Secondary fungal infection of the bark is seen which cause shredding and peeling of the bark.

The result of the studies on biometry of galled plant parts revealed that the weight of the plant parts increased significantly due to the infestation by EGW. The length of the petioles decreased to one third where as the girth of the petioles almost doubled the normal values. The biomass of the terminal and lateral leaflets also increased by two fold due to the increase in tissue growth. The emergence of wasp population was maximum from petiole samples graded in the damage category '9' (37.3 ± 14.29).

Histological studies of the galled plant parts showed

- Increase in the size of the cell or losing of the cell shape.
- Degeneration of the palisade tissue in leaf.
- Arrangement of palisade tissue altered.
- Compressed vascular bundles in the petioles.
- Degeneration of ground tissue leading to the formation of hollow pith.
- The gall cavity is lined by closely packed cells.
- The gall cavity is filled with nutritive tissue devoid of chlorophyll.

The hand sections of the galled petioles showed various life stages of EGW, carrot shaped milky white larva, initial white coloured exarate pupa and pupa showing laterally projecting red eyes. The male EGW was slender when compared to females. The females are stout and larger in size. The result of the studies on activity, movement and oviposition behavior of the adult EGW showed that male EGW was more active than the female wasps. Among the plant parts compared for the preference for oviposition, the buds, unopened leaves and petioles were found to be the most preferred sites for oviposition.

The results of the laboratory evaluation to assess contact toxicity of insecticides showed that thiomethoxam, imidacloprid, acephate and carbaryl were the most toxic in killing the wasp at very low concentrations.

The results of studies of botanicals for the control of gall wasp infestation revealed that neem oil garlic 2 per cent and neem oil 2 per cent protected the new shoots up to 26 to 29.33 days. Studies on the systemic and translaminar effect of insecticides to the insect inside the gall showed that triazophos 0.05 per cent, imidacloprid 0.002 per cent, acetamiprid 0.003 per cent and thiomethoxam 0.002 per cent were equally effective in killing the wasps.

The results of the field experiments revealed that application of dimethoate 0.05 per cent alone or in combination with carbendazim 0.2 per cent, carbaryl 0.1 per cent, neem oil 2 per cent, neem oil garlic 2 per cent, and imidaclorpid 0.002 per cent + carbendazim 0.2 per cent effectively protected the side shoots, from EGW infestation.

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APPENDIX

Appendix

Weekly weather parameters recorded during January 2006 – June 2007

Period	Temperature ^0C		Relative humidity (%)		Rainfall (mm)
	Max.	Min.	Max.	Min.	
1 Dec 2005	32.1	23.4	95.0	74.7	60.6
2 Dec 2005	31.7	23.1	93.7	70.1	61.2
3 Dec 2005	29.5	22.7	95.6	80.0	90.8
4 Dec 2005	30.8	23.4	95.1	67.0	4.9
5 Dec 2005	31.9	21.6	95.1	65.9	0.0
1 Jan 2006	32.1	22.8	91.5	68.2	0
2 Jan 2006	32.2	23.7	93.4	66	13.2
3 Jan 2006	28.6	20.9	96	69	9.3
4 Jan 2006	31.2	21.7	93	72.1	0
5 Jan 2006	31.6	22.4	90.3	75	0
1 Feb 2006	32.1	22.1	91	73.4	0
2 Feb 2006	32.2	22.6	91.2	61.1	0
3 Feb 2006	32.5	23.2	94	61.6	0
4 Feb 2006	31.6	23.9	92.6	64.9	4.1
1 Mar 2006	33.3	23.6	94.4	70.6	24.2
2 Mar 2006	31.9	25.2	94.4	62	0
3 Mar 2006	32.8	24.6	96	65.6	1.1
4 Mar 2006	32.8	24.5	95.9	68.6	1
1 April 2006	33.6	24.9	95.9	75.3	0
2 April 2006	32.8	26	89.7	68.7	8.9
3 April 2006	32.3	25.5	91.5	72.5	24.6
4 April 2006	33.3	27.2	91.3	67.3	0.8
1 May 2006	33.3	26.4	82.7	71	0
2 May 2006	33.3	26.3	87.8	69.5	33
3 May 2006	32.3	25.8	92	75.5	2.9
4 May 2006	29.7	23.7	93.2	81.8	117.5
5 May 2006	30	23.5	95.8	86	131.7

Period	Temperature ^0C		Relative humidity (%)		Rainfall (mm)
	Max.	Min.	Max.	Min.	
1 Jun 2006	31.2	25	90.5	77.8	0.5
2 Jun 2006	32	24.5	90.3	73.2	0
3 Jun 2006	30.6	23.5	93.3	79	169.8
4 Jun 2006	28	27.4	82.8	69.4	2
1 Jul 2006	29.7	23.1	95	85.3	138.8
2 Jul 2006	29.2	23.8	91.3	80.8	14.8
3 Jul 2006	30.5	25.4	91.2	71.4	3.3
4 Jul 2006	29.9	23.8	88.8	78.2	0
1 Aug 2006	30.8	24	91.5	72.5	3.5
2 Aug 2006	29.8	23.4	93.5	81	34.3
3 Aug 2006	28.9	23.2	96	81.8	72.4
4 Aug 2006	30.8	20.8	91.3	84.2	0
5 Aug 2006	30.4	23.3	91.6	75.1	1.5
1 Sep 2006	31	21.9	89.6	82.1	11.8
2 Sep 2006	29.8	22.7	89.7	78.6	94.1
3 Sep 2006	29.7	22.8	95.6	81.33	167.7
4 Sep 2006	30.3	23	92.4	79.1	105.4
1 Oct 2006	30.4	23.1	93.4	83.1	39.9
2 Oct 2006	30.5	23	90.6	83.7	86.1
3 Oct 2006	30.4	22.7	96.3	79.3	176.3
4 Oct 2006	29.6	22.8	97	80.9	194.3
5 Oct 2006	29.4	22.3	96.4	81.3	110.8
1 Nov 2006	30	25.4	94.4	81.3	46.6
2 Nov 2006	29.9	23.1	94.5	83.9	54.3
3 Nov 2006	31.3	22.3	94	74.9	82.7
4 Nov 2006	31.8	23.1	96.7	72.1	23.6
1 Dec 2006	30.8	21.8	96.3	65.9	0
2 Dec 2006	31.6	22.4	96.7	74.1	6

POPULATION DYNAMICS AND MANAGEMENT OF ERYTHRINA GALL WASP

Quardrastichus erythrinae Kim.

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ABSTRACT

Studies were conducted to understand the population dynamics and management of Erythrina Gall Wasp (EGW) *Quadrastichus erythrinae*. An abstract of the work done and the results obtained are given below.

Population dynamics of *Q.erythrinae* was studied by observing weekly emergence of male and female insects from leaflets and petioles collected from field during the period from January 2006 to June 2007. The results showed that population was high in the months of July 2006, January 2007, April 2007 and June 2007.The present study indicated that the emergence of adult EGW was the highest from petioles. The increase in weight due to EGW infestation and gall production was the highest in the left lateral leaflets.

Weekly mean population of EGW emerged during the period of study showed that the total number of male EGW (1096.36) was higher than the female insects emerged (763.13). Weekly mean population of the male and female emerged from the leaflets and petioles was correlated with weather parameters viz. maximum and minimum temperature. Maximum and minimum relative humidity and rainfall prevailed during the time of sampling, previous one week, previous 14 days,week 21 days before and week 28 days before. The results showed significant and positive correlation between population of male EGW and the minimum temperature, while no correlation existed between female population and other parameters studied.

Comparison of biometric observation of uninfested and infested plant parts indicated that the weight of the leaflets and petioles increased significantly due to an increase in biomass. Due to galling by EGW, the girth of the petioles was shortened

to about one third of uninfested petioles. The emergence of EGW was maximum from petioled scored in the damage category '9'. Among the four groups of *Erythrina stricta* Roxb. trees studied, based on the height of the trees, no group turned out to withstand the damage by EGW.

Thiomethoxam, imidacloprid, carbaryl and acephate proved superior among the chemical insecticides tried against female and male EGW in the laboratory. Neem oil 2 per cent and neem oil-garlic 2 per cent proved superior among the botanical insecticides tried for protecting the newly formed side shoots. Among the systemic /translaminar insecticides applied on the galled plant parts, triazophos 0.05 per cent and imidacloprid .002 per cent were significantly superior in controlling the EGW emergence.

In the field experiment conducted to evaluate insecticide-fungicide combination for EGW infestation and protection of the new side shoots, carbaryl 0.1 per cent and combination of imidacloprid 0.002 per cent and carbendazim 0.2 per cent effectively protected the side shoots up to 8 weeks after spraying. Residue analysis of dry pepper berries collected from pepper vines trailed, on the insecticide sprayed erythrina standards showed that residues at the time of harvest from trees sprayed with acephate 0.05 per cent dimethoate 0.05 per cent were below detectable limit. Where as the residues in pepper collected from lamda cyhalothrin 0.05 per cent and triazophos 0.05 percent treated trees was 1.38 ppm and 1.16ppm respectively.

An overall analysis and interpretation of the data on population of EGW in relation to the phenology of *E .stricta* showed that there existed a six monthly cycle of damage by gall wasp, resulting in complete defoliation of the trees by about six month followed by the next cycle of regrowth and re infestation .