INTRODUCTION

Ecosystems are characterized by a huge diversity of species and a corresponding diversity of interactions among these species. Ecological studies have been dominated by interactions between two trophic levels, in particular, plant-herbivore and predator - prey interactions. Price et al., (1980) stated that one cannot understand the plant herbivore interactions without understanding the role of natural enemies of insect pests and one cannot understand the prey - predator relationships without understanding the role of plants. The attack of herbivorous arthropods is a serious matter for a plant. The outcome of such plant - herbivore encounters is influenced not only by the plant inherent defenses but also by the action of the third trophic level namely, the predators, and parasitoids that attack herbivores (Whitman and Nordlund, 1994).

The tritrophic interactions among plants, herbivores and natural enemies are governed by integrated host plant resistance, biological control in the management of arthropod pests and their direct and indirect interactions in ecological communities. The physical, chemical and nutritional qualities of plants affect the attack rate, survival and reproduction of natural enemies by influencing the distribution, abundance and vulnerability of herbivores (Tscharntke and Hawkins, 2002).

Moriculture, the cultivation of mulberry, is the basement of sericulture. The leaf of mulberry is the basic food of silkworm, *Bombyx mori* L. Silkworm
converts the green mulberry leaves into glorious silk. The role of leaf quality is very important in the success of silkworm rearing and cocoon production (Dandin et al., 2001). Mulberry being an evergreen perennial plant with luxuriant foliage, affords an unlimited source of food and shelter for a variety of insects. Pests often hamper the production of appreciable quantity of quality mulberry leaves. Mulberry is attacked by more than 300 species of insects of which the tukra mealy bug, *Maconellicoccus hirsutus* (Green) (Homoptera: Pseudococcidae) is found to be more destructive (Rajadurai and Thiagarajan, 2003). Tukra symptom of leaf crinkling, curling and crowding at the shoot terminals is caused due to the infestation of mulberry plants by the mealy bug (Reddy and Kotikal, 1988). Tukra affected leaves had adverse effect on the silk worm rearing performance, caused a significant decline in the commercial characters like larval weight, effective rate of rearing, cocoon weight, shell weight and silk ratio. (Kumar et al., 1992).

*M. hirsutus* is a polyphagous hard to kill pest. Chemical and mechanical control methods, which are in practice now, have many limitations. Biological control is the only viable alternative for sustainable sericulture but is also not much effective.

There is often pest mismanagement in the country through the loss of biological control agents, overdosing with pesticides leading to development of resistance, higher chemical inputs, introduction of pest susceptible crop varieties
and hybrids, large monocultures, unbalanced irrigation, and agronomic changes like abandonment of cultural control (Jayaraj, 2003). According to Swaminathan (2002) the inefficient use of inputs, particularly water, nutrients, and pesticides is increasing the cost of cultivation, without any corresponding yield dividend. With a view to promote sustainability of crop production, it is very important to develop and adopt low cost systems of integrated pest management programmes with biological control as the foundation (Jayaraj et al., 1995). The natural enemies of insect pest play a key role in biotic balance, reducing levels of pest population below the economic injury level. Both the natural and applied biological control tactics are important in successful management of pest population. Pest avoidance and pest monitoring would be important on the basis of tritrophic relations among the cultivars, host insects and the entomophages. (Jayaraj, 2003).

These tritrophic interactions are heavily influenced by biological characteristics of the second and third trophic level, host plant characters, the alternate hosts of herbivores, the diversity of the insects in the ecosystem, and the biotic and abiotic factors. Hence in the present study the tritrophic relationship among the host plant, insect pest and its natural enemies and, the factors influencing the above relations were studied in order to increase the efficiency of biological control methods.
The present study was conducted at Kanyakumari district in the southern most side of Tamil Nadu state, India, situated between $77^\circ 05'$ and $77^\circ 26'$ of the eastern longitudes and $8^\circ 03'$ and $8^\circ 35'$ of the northern latitudes with an altitude of 131m above mean sea level. The district is unique in its biogeography, receives both the South-West monsoon (June-July) and North East monsoons (September-October). Even though sericulture is practiced in large scale in Karnataka and neighbouring districts in Tamilnadu; presently the industry is getting momentum in southern Districts. The mulberry acreage in this district is also improving. The polyphagous pest, *M. hirsutus* is found to be very serious and is to be managed properly.

The study entitled "Studies on the tritrophic relationships among mulberry, tukra mealy bug, and its entomophages for sustainable sericulture" includes the study on biology of mealy bug, its predators and parasitoid, predatory potential and host preference of predators, symptoms caused by the infestation of the mealy bug, alternate hosts, varietal influence on the tritrophic relationship, influence of leaf characters, diversity of insects in mulberry garden influencing the relations, mutualism between mealy bug and ants, population dynamics of mealy bug in mulberry, influence of biotic and abiotic factors in mealy bug population and its natural enemies. The details of the study are explained below.
Biology of *Maconellicoccus hirsutus* was studied as basic to study the tritrophic relations. Biology of mealy bug and their predators was studied on the host mulberry. The incubation period, nymphal period, total developmental period, adult longevity, fecundity of the mealy bug and feeding potential of the entomophages were investigated. The morphological studies of mealy bug were done using the scanning electron microscope (SEM).

The feeding damage and symptoms caused by the mealy bug in the mulberry were studied. The piercing and sucking type of mouthparts of mealybugs were observed under SEM. The reasons for the preference of the tender leaves by the mealy bug were assessed by analyzing the biochemical contents of tender, medium and coarse leaves. The specific symptoms developed, damages in different mulberry varieties and in alternate hosts were studied. The biochemical content of healthy leaves and mealy bug infested leaves were analyzed separately in the five selected varieties. Difference in the protein profiles of healthy leaves and tukra infested leaves were analyzed by SDS polyacrylamide gel electrophoresis.

The mealy bug - natural enemies interactions on different host plants were studied for pest avoidance and natural control of the mealy bug. The different alternate host plants selected were hibiscus (*Hibiscus rosasinensis*), ladies finger (*Abelmoschus esculentus*), guava (*Psidium guajava*), gliricidia (*Gliricidia sepium*), and the sensitive plant (*Mimosa pudica*). Seasonal incidence of mealy bug
and its natural enemies were studied on these host plants and statistically compared with mulberry, to find out the best preferred host. The other host plants in the surroundings of mulberry garden were also observed throughout the study period for mealy bug incidence.

A mulberry garden with five cultivated varieties was established in randomised block design. The popular varieties such as TN local, MR2, K2, S36 and V1 were grown for the comparative studies. The percentage of mealy bug infestation, mealy bug population, and natural enemies population on these varieties were counted fortnightly and tabulated. Similar work was carried out in the potted plants under the green house also. The preference of mulberry by mealy bugs in different days of crop growth was also analyzed. The varietal preference of mealy bugs and natural enemies were statistically analyzed. Olfactometry studies were done to find out the predator preference.

The biochemical components such as chlorophyll, protein, total soluble sugars, amino acids, carbohydrates, and phenol of mulberry leaves were analyzed and correlated with the tritrophic relationship. Trichomes present on leaf surface were counted and their influence on the host preference of pest and natural enemies were analyzed.

Studies on diversity are the preliminary step in any management works. Hence a study was conducted in mulberry ecosystem to survey the diversity of the insects and to find their impact on tritrophic relations. The taxonomic
diversity, trophic structure of the insect communities and diversity indices were worked out. The insect herbivores, carnivores, naturals and detrivores enhancing the density of carnivores were studied for two continuous years in the mulberry garden. Species richness, evenness, abundance, dominance and diversity indices were worked out.

The occurrence, abundance, and incidence of mulberry pest are expected to be influenced by both biotic factors like parasitoids, predators, and pathogens and abiotic factors like temperature, relative humidity, rainfall and rainy days. In the present study, tritrophic relations of plant infestation, mealy bug population, and natural enemies abundance were correlated with the effect of temperature, relative humidity, rainfall, and rainy days.

A simple forewarning system for tukra mealy bug was developed and the possibility in the integrated pest management of mealy bug was also indicated for the sustainable sericulture.
REVIEW OF LITERATURE

The main goal in research on tritrophic interactions in applied systems is to determine whether biological control can be combined with host plant resistance in developing a more highly integrated pest management programmes (Hare, 2002). The majority of food webs associated with living plants involve at least three trophic level interactions; plants herbivores, and the natural enemies. The natural enemies of herbivores benefit the plants by reducing herbivore abundance, while plant may benefit the herbivore's enemies by making herbivores more vulnerable to the natural enemies (Ananthakrishnan, 1992).

Host-plant resistance and biological control are considered to be cornerstones of integrated pest management programs, but there are few studies that elucidate the intricate relationships among host plant, phytophagous insect and natural enemies. Knowledge of interactions in systems that include three or more trophic levels is limited, yet the need for such knowledge is greatly needed for understanding how selection forces shape these relationships, and for knowing how systems can be beneficially manipulated (Lenteren-van et al., 1995). The literatures on studies on the tritrophic relationships among mulberry, tukra mealy bug *Maconellicoccus hirsutus* and its entomophages for sustainable sericulture are reviewed here.
The interactions between plants, herbivores and natural enemies

Janssen et al., (1998) stated that with the increased use of biological control agents, artificial food webs are created in agricultural crops and the interactions between plants, herbivores and natural enemies change from simple tritrophic interactions to more complex food web interactions. Therefore, herbivore densities will not only be determined by direct predator - prey interactions and direct and indirect defense of plants against herbivores, but also by other direct and indirect interactions such as apparent competition, intraguild predation, resource competition, etc.

Coleman et al., (1999) studied the effect of host feeding site on the potential host-finding success of the braconid parasitoid Cotesia glomerata in the tritrophic system of Brassica oleracea - Pieris brassicae - C. glomerata and found that parasitoids were most attracted to plants with herbivores feeding on the upper foliage, less attracted by mid-plant herbivory and incapable of distinguishing between control plants and plants with herbivory on the lowest leaves. The experiments done with artificial plants by Gingras et al. (2002) revealed that plant structure affected host-finding success, which was higher on plants with a simple structure and lower on plants with a complex structure.
Freier and Triltsch (1996) investigated the tritrophic interaction among winter wheat - *Sitobion avenae* - *Coccinella septempunctata* in climate chamber experiments with defined population sizes and three temperature regimes and found that an increase in temperature from 20 to 22°C enhanced the intrinsic rate of increase of aphid populations. However, simultaneously the feeding rate of coccinellids increased much more relatively and therefore aphid infestation was reduced. The decrease in aphid density was not only the result of higher predator effectiveness but also faster ripening of wheat. The results indicated that rise in temperature up to 25°C could enhance the natural control of aphids by coccinellids.

The recognition and selection of hosts, oviposition success, clutch size decisions and the adjustment of sex ratios are considered as some of the basic responses by parasitoids to physical factors associated with their hosts or the local environment of the host (Schmidt, 1991). Predators and prey are usually heterogeneously distributed in space so that the ability of the predators to respond to the distribution of their prey may have a profound influence on the stability and persistence of a predator-prey system (Nachman et al., 2001).

Secondary plant metabolites (allelochemicals) play a major role in plant-insect-natural enemies interactions. Secondary plant metabolites in host plants can affect parasitoids directly or indirectly through their action on the parasitoid host. Reitz and Trumble (1996) conducted studies to determine the linear
furanocoumarins, psoralen, bergapten and xanthotoxin, secondary plant metabolites present in *Apium* spp. and other taxa, and stated that they exerted direct or indirect effects on *Copidosoma floridanum*, a polyembryonic parasitoid of *Trichoplusia ni*, through diet incorporation bioassays. The differential effects on the host and parasitoid, linear furanocoumarins, at naturally occurring concentration, can mediate this host-parasitoid relationship through direct effects on the parasitoid, and not merely as a consequence of their effect on the host.

The host - plant resistance will not always positively contribute to the suppressive effect of natural enemies. A study of the relationships among cucumber, *Trialeurodes vaporariorum* (Homoptera; Aleyrodidae) and its parasitoid *Encarsia formosa* (Hymenoptera; Aphelinidae) illustrated the selection of less hairy plants leading to the finding and killing of more hosts per unit time by the parasitoid and thus improved biological control. Leaf hairs reduce the capacity of *E. formosa* to control greenhouse whitefly on cucumber (Lenteren-van and Van-Lenteren, 1991).

Vanhaelen *et al.*, (2002a) studied the prey host plant influence on reproduction of an aphidophagous beneficial, the two-spot ladybird *Adalia bipunctata*, using the cabbage aphid, *Brevicoryne brassicae* reared on a crucifer plant, namely *Brassica napus* containing low glucosinolates(GLS) levels. As ladybird developmental and reproductive parameters were already strongly affected by the allelochemical presence in its preys, the unsuitable aphid and
host plant combination was only momentary used to feed the *Adalia bipunctata* adults. A strong impact of the diet was observed on the beetle fecundity and the emerging offspring. Changing from a *Brevicoryne brassicae* aphid to a suitable prey slowly improved the temporary negative effect of the former diet. These results enhance the food environmental effect and the importance of tritrophic relations in pest management strategies by predators. Indeed, more than the choice of the beneficial species, the prey host plant has a major influence on the potential efficacy of the biological agent to control herbivore species.

Vanhaelen, *et al.*, (2002b) observed glucosinolates and their degradation products from *Brassica* species as attractants and feeding stimulants for Brassicaceae specialist insects but are generally repellent and toxic for generalist herbivores. The influence of the prey's host plant on both development and reproduction of the hoverfly *Episyrphus balteatus*, was determined using the cabbage aphid, *Brevicoryne brassicae* (a specialist) and the peach aphid *Myzus persicae* (a generalist) reared on two crucifer plants, *Brassica napus* and *Sinapis alba* containing low and high GLS levels, respectively. The prey and its host plant differently influenced life history parameters of *E. balteatus*. The predator's rates of development and survival did not vary when it fed on the generalist aphid reared on different host plants. However these rates decreased, when the predator fed on the specialist aphid reared on the host plant with high GLS content versus the host plant with lower GLS content. This aphid host plant
combination also negatively affected hoverfly reproduction and fecundity. The fitness of the hoverfly was also strongly affected. This study illustrates the importance of tritrophic relations in pest management involving predators. The host plant of the prey can have a major influence on the potential of a biological agent to control herbivore species.

Plant volatiles also mediate tritrophic interactions. The effects of plant-plant interactions via volatiles (aerial allelopathy) on herbivores and their natural enemies were investigated by Ninkovic (2002) with the model system consisted of four barley varieties, an aphid pest, *Rhopalosiphum padi* (L.), and a common aphid predator, ladybird *Coccinella septempunctata* (L.). He observed that the four barley cultivars used did not differ in aphid attractivity and acceptance when tested separately but caused significant changes in specific cultivar combinations by aerial allelopathy in both laboratory and field experiments. Olfactometer experiments with ladybird showed that aphid-attacked plants and previously attacked plants with the aphids removed were more attractive than undisturbed aphids or undamaged plants. He concluded that plant-plant interaction in the barley-weed-aphid-ladybird system has a significant effect on each trophic level i.e. plant physiology and development, aphid host plant relations and the searching behaviour of a common predator.

Reed *et al.*, (1991) evaluated the tritrophic interactions among resistant and susceptible barley, triticale and oats, *Diuraphis noxia* (Homoptera: Aphididae)
and a hymenopterous parasitoid *Diaeretiella rapae* McIntosh and their efficacy in reducing the damage to these food plants showed that there was a significant decrease of *D. noxia* in the plant entries tested when a single parasitoid was allowed to oviposit for 24 h. A high level of antibiosis was observed in the resistant triticale.

Murugan *et al.*, (2000) observed an increased reproductive period, total life span and reproduction of nymphs per female of *Aphis nerii* when reared on mature leaves of *Calotropis gigantea* and aphids reared on leaves of different stages influenced its predator's (*Menochilus sexmaculatus*) growth, prey utilization and reproductive performance. Fecundity and longevity were high, while the developmental time of predators was shorter when fed on aphids reared on mature leaves.

**Pest menace in sericulture**

The breakthrough in sericultural development was mainly due to the introduction of many silkworm hybrids, high yielding mulberry varieties and adoption of improved crop production technologies. For a sustainable sericulture the productivity of the sericultural farms should be increased. The role of leaf quality is very important in the success of silkworm rearing and cocoon production. Feeding the infected leaves of plants to the silkworms adversely affect their growth and health resulting in partial or sometimes complete failure of silkworm crops and reduced marketing quality of cocoons produced (Dandin
et al., 2001). The production of appreciable quantity of quality mulberry leaves is often hampered by the infestation of mulberry garden by more than 300 species of insect and non insect pests belonging to a large number of insect orders (Rajadurai and Thiagarajan, 2003). Dandin et al., (2001) listed leaf roller Diaphania pulverulentalis (Hampson), tukra mealy bug Maconellicoccus hirsutus (Green), hairy caterpillar Spilosoma obliqua Walker, wingless grasshopper Neoorthacris acuticeps nilgirensis Uvarov and cutworm Spodoptera litura F. as the serious pest of mulberry. Other important pests recorded on mulberry are thrips Pseudodendrothrips mori (Manjunath and Shree, 2001), spiraling white fly, Aleurodicus dispersus (Russel) (Jagadish et al., 2001), jassid, Empoasca flavescens (F.) and scale insect Saissetia nigra (Manjunath et al., 1993).

Tukra mealybug infestation

However in recent years mealy bug infestation is found to be more destructive owing to the extent of qualitative and quantitative damage to mulberry leaves (Manjunath et al., 1993). The pink mealy bug M. hirsutus is recorded in more than 350 hosts (Ghose, 1972; Mani, 1988; Persad 1995; Rajadurai and Thiagarajan, 2003). Though the pest infests majority of the mulberry plantation in South India, the infestation is severe in Tamil Nadu (Baskaran et al., 1994). The pest infests most of the commercial mulberry varieties (Manjunath et al., 1993). Mealy bug infestation is found in all the stages of mulberry growth (Ali 1995). The infestation of mulberry plants by the sap feeding mealy bug, M.
hirsutus (Green) (Hemiptera; Pseudococcidae) causes tukra (Reddy and Kotikal, 1988). The characteristic symptoms of tukra are crinkling, curling, and dark green leaves at the apices, bushy top due to the arrest of linear growth with thickening and twisting of affected shoots leading to considerable loss of leaf yield (Kumar and Chakraborthy, 1999). Morphologically, linear growth of the stem and petiole was arrested and their thickness increased. The leaf lamina was markedly reduced and distorted. Histologically, the cells were enlarged and suffered reduced lignification. There was an increase in the number of stomata, which varied in the different plants (Ghose, 1972). Mulberry leaves affected by 'tukra' showed negligible decreases in protein, starch and carbohydrate, whereas reducing sugar and total sugar contents slightly increased (Zaman, 1996). Percentage of moisture content, total lipids, total proteins and soluble carbohydrates were greater in tukra leaves compared to healthy leaves (Veeranna, 1997).

The yield loss of mulberry ranged from 2.45 to 44.33 per cent depending upon the intensity of mealy bug infestation (Sugunakumari et al., 2000 and Veeranna et al., 2001). Muthulakshmi et al., (2004) reported 50.6 per cent damage during summer months.

The important reason attributed for mealy bug out breaks are continuous cultivation of susceptible varieties, certain cultural practices, ecological factors and ever increasing application of chemical pesticides which were not effective
in controlling the pest but, disrupted their natural enemies, resulting in pest resurgence (Manjunath, 1986). In India severe out breaks of mealy bug, *M. hirsutus* was reported from Andra pradesh in Grapes during late seventies (TejKumar *et al.*, 1977 and Satyanarayana, 1981) and subsequently in Karnataka, Maharashtra and Tamilnadu in all crops (Radha and Muthukrishnan, 1980; Manjunath, 1985; Baskaran *et al.*, 1994 and Ali 1995). The insecticides used to control mealy bug failed, but cleared the natural enemies population in the garden. Still mealy bugs are hard to kill pests (Lower, 1968). The mealy bugs habitat and the mealy coating protect themselves from the pesticides. The mechanical control of clipping the affected twig cause qualitative and quantitative damage in leaf production. On the other hand mealy bugs being sessile, they are more amenable to biological control in which parasitoids and predators can effectively reduce the mealy bug population (Mani, 1989).

**Biology of tukra mealybug**

Adult mealy bugs are small and pink in body colour covered with white waxy secretion. Female die shortly after depositing eggs. Each female deposits 350 to 500 eggs in loose cottony terminal ovisac during a week's time. These eggs are orange in colour hatch in 5 - 10 days. First instar nymphs called crawlers disperse by walking or by wind. A generation is usually completed in a month but extended in winter months. (Ghose, 1972; Manjunath *et al.*, 1993 and
Gautam, 1994). Serrano et al., (2001) reported that males of *M. hirsutus* were attracted by sex pheromones of virgin males.

The mealy bug *M. hirsutus* forms a typical example of sexual dimorphism. Adult males are slender, elongated and possess a pair of wings. The females are oval flat and devoid of wings and caudal filament. Males move actively in the colony, females are sluggish and the nymphs are gregarious in nature. The active crawlers move towards the apical portion of the plant, settle there to suck out the juice from the plant with the help of needle like mouthparts (Manjunath et al., 1993). It takes shelter in the protected area of the host such as cracks and crevices of bark, at the base of leaf petioles, on the underside of leaves, in the wrinkles of leaf etc. As a result the pest becomes less accessible to the spray of pesticides. Even if exposed the waxy filamentous coating protect the insect from the chemicals (Mani, 1989). Keeping in mind the hazardous effect of pesticides, the cultural and biological control measures get more momentum.

**Entomophages of tukra mealybug**

Mealy bug is prone to attack by several parasitoids and predators. Mani, (1989) and Noyes and Hayat, (1994) reported 24 hymenopteran parasitoids, 23 coleopteran predators, five dipteran predators, one hemipteran predator and seven neuropteran predators to attack *M. hirsutus*

Among them *Anagyrus kamali*, *A. dactylopii*, *Leptomastix dactylopii*, *Cryptolaemus montrouzieri*, *Menochilus sexmaculatus*, *Nephus regularis*, *Chrysopa* sp,
Mallada boninensis and Scymnus coccivora are found to be effective in normal climatic condition (Mani, 1988; Sagara and Peterkin, 1999; Persad and Khan, 2002 and Rajadurai and Thiagarajan, 2003). Goolsby et al., (2002) reported that M. hirsutus is under excellent natural control by predators and parasitoids and rarely reaches pest status in Australia and C. montrouzieri is the key natural enemy. Joshi et al., (2003) emphasized that lady bird beetles are the most important group of predators of mealy bugs. Crawley (1990) stated that the generalist predators like spiders and anthocorid bugs are more important than the immigrant lady birds. These generalist one are active early in the year and can nip the insect out breaks in the bud, either by killing the founder insects or by exterminating small colonies. The predators like lady birds and parasites immigrate into the crop only after the insect population built up. Ahmed and Malik (1987) reported that spiders belong to four families control the mulberry pests. The population of predator increased with pest population (Ooi, 1980).

C. montrouzieri is called mealy bug destroyer feeds on egg, nymphs and adult of M. hirsutus. Dichlorvos and chlorpyriphos are relatively nontoxic (Mani, 1988; Mani, 1989; Ramkishore et al., 1993; Jalai et al., 1999; Muralibaskaran et al., 2002 and Masilamani et al., 2003).

Scymnus coccivora is a common coccinellid predator found feeding on M. hirsutus colonies in pesticide free zones. (Mani and Thontadarya, 1987; Katiyar and Sen, 1998; and Muralibhaskaran et al., 2006). Santhakumar and
Chakraborty, 1997 reported *S. nubilus* as a potential predator of *M. hirsutus*. The Coccinellid *Nephus* sp was reported as potential predator of *M. hirsutus* by Chakraborty *et al.*, (1999).

The parasitoids *A. dactylopii* and *A. kamali* are very effective in controlling mealy bug population in coordination with coccinellids. These belong to the family Encyrtidae of order Hymenoptera. *A. dactylopii* found to parasitize 70 per cent of *M. hirsutus* on grapes. *A. kamali* also parasitizes 60 – 100 per cent of *M. hirsutus* population (Mani, 1989; Noyes and Hayat, 1988; and Katiyar and Sen, 1998). Experiments conducted by Sagarra and Vincent (1999) to investigate host stage selection and suitability by *A. kamali* parasitizing *M. hirsutus* revealed that all nymphal stages and the adult female of the host could be parasitized. Sagarra *et al.*, (2000b) reported that *A. kamali* can be stored at 20 ± 2°C without affecting its longevity, oviposition and foraging activities which help in preserving the parasitoid in unfavorable conditions.

Katiyar and Sathyaprasad, (2007) reported that *A. kamali* can be exploited as a bio-control agent of mealy bug as it can parasitize all stages of *M. hirsutus* and prefer later stage of mealy bugs which is important in the management of *M. hirsutus* as majority of these stages are females which contribute to the rapid colonization of the pest.
Influence of different host plants on tritrophic relations

Several researchers have reported on variation in biological parameters in herbivores on different hosts. Host plant nutritional factors not only influence herbivore growth and survival, but also indirectly alter the fitness of parasitoids through change of herbivore quality (Ananthakrishnan, 1990). Hare, (1992) explained four types of interactions existed between host plant variations, herbivore, and natural enemies. Moreover he summarized that antagonistic interactions were slightly more frequent than additive interactions, while synergistic interactions were rare and no disruptive interactions were identified.

Woets and Vanlenteren (1976) attributed differences in white fly populations on different host plants as a combination of the effect of the host plant on pest fecundity, lifespan, and development rate. Growth, development and fecundity of citrus mealy bug, Planococcus citri (Risso), differed substantially when fed on red, yellow or green leafed Coleus bluei (Bentham) (Yang and Sadof 1997). Megacopta cribraria ( Fab) (Hemiptera; Plataspidae) feeding on Sesbania grandiflora realized higher fecundity and survival as a result its life table characteristics such as net reproductive rate and intrinsic rate of natural increase on this plant were significantly higher than on Crossandra undulaefolia Salisb and Gossypium hirsutum L. (Srinivasaperumal et al., 1992). Srinivasaperumal and Samuthiravelu, (1992) stated that the Pericallia ricini (Fab) (Arctiidae :
Lepidoptera) reared on three hosts preferred *Ricinus communis* than *Musa indica* and *Moringa oleifera*. Louda, (1998) suggested that the ecological characteristics such as phenology influenced the host preference and population growth of *Rhinocyllus conicus* (Coleoptera: Curculionidae) on two species of native thistles in Prairie.

The oligophagous, multivoltine stem borer *Nephopteryx divisella* (Lepidoptera: Pyralidae) which is a weed biocontrol agent of *Euphorbia esula* L. a major weed in North America also preferred other species of *Euphorbia* which are economically important. The egg fecundity and biological parameters were better in *E. millii* and *E. biglandulosa* (Christofaro et al., 1998). Setamou et al., (2000) studied the population dynamics of the ear borer *Mussidia nigrivenella* (Lepidoptera: Pyralidae) in different host plants and stated that maize and cotton are suitable hosts. Ofomata et al., (2000) compared the fecundity, egg survival, larval feeding and development of *Chilo partellus* and *C. orichalociliellus* (Lepidoptera: Crambidae) on five grasses and reported *C. partellus* could develop on maize, sorghum and wild sorghum whereas *C. orichalociliellus* developed on maize, sorghum, wild sorghum, napier grass and guinea grass. Ngi- song et al., (1996) found that the parasite *Cotesia flavipes* of *C. partellus* and *C. orichalociliellus* was attracted to odors from uninfested maize sorghum and napier grass and even more attracted to the same three grasses infested with stem borers.
Ru and Souissi (1998) studied the influence of the cassava, the host plant of the mealy bug, *Phenacoccus manihoti* (Hemiptera: Pseudococcidae) on biological characteristics of its parasitoid *Apoanagyrus lopezi* (Hymenoptera: Encyrtidae) and stated that the mortality of *P. manihoti* due to host feeding by the adult parasitoid and percentage of parasitization of *P. manihoti* were significantly lower when reared on two cultivars of cassava, and the hybrid than when reared on *Talinum triangulare*, a common weed in cassava field. *A. lopezi* performed better if cassava cultivars were selected for their strong antixenosis but low antibiotic characteristics. Ru and Mitsipa (2000) reported that the life history parameters of the generalist predator, *Exochomus flaviventris* were greatly affected by the host plant of the prey species *P. manihoti*. *P. manihoti* fed on a hybrid cassava Faux-caoutchouc, cassava variety Incoza were less suitable prey than those fed on the cassava variety Zanaga and a weed *Talinum triangulare*. Souissi *et al.*, (1998) studied the tritrophic interactions between host plants, the *P. manihoti*, and its parasitoid *A. lopezi* and reported that the percentage parasitism of *P. manihoti* by *A. lopezi* varied significantly between host plants and higher on *Talinum triangulare* than on the plants of the *Manihot* genus.

Heidari (1999) studied the predation of obscure mealy bug *Pseudococcus viburni* by two coccinellid predators viz., *C. montrouzieri* and *N. reunioni* on *Citrus limon*, *Coffea arabica*, *Lycoperisicon esculentum*, *Passiflora caerulea*, *Solanum tuberosum* and *Streptocarpus* sp. and reported *C. montrouzieri* showed good control
of mealy bug irrespective of the hairiness of the plant species, although
*N. reunioni* was more effective on smooth leaves than hairy leaves.

Persad and Khan, (2007) evaluated the effect of four host plants on
biological parameters of *M. hirsutus* and efficacy of *A. kamali*. The *M. hirsutus*
reared on *Hibiscus rosasinensis* and *Hibiscus sabdariffa* had shorter life cycles and
highest survival percentage than on *Solanum tuberosum* and *Cucurbita pepo*. He
also revealed that *M. hirsutus* infested on *H. rosasinensis* and *H. sabdariffa*
produced *A. kamali* with significantly higher fecundity and lower longevity
compared to the other host plants. *A. kamali* efficacy measured by per cent
parasitization and per cent adult eclosion was statistically similar for all
*M. hirsutus* infested host plants tested.

**Influence of different varieties on tritrophic relations**

The improvements in the mulberry varieties had increased the leaf
production per unit area. These improvements have also paved way for their
susceptibility to attack by pests. Srinivas *et al.*, (1996) reported that mulberry
varieties differ in their susceptibility to infestation by *M. hirsutus*. Shree and
Boraiah (1988) screened 43 varieties of mulberry and found 18 exotic varieties
were resistant to tukra. Sathyaprasad *et al.*, (2002a) screened mulberry varieties
for sucking pests and indicated Togowase was tolerant to all the sap suckers.
Sathyaprasad *et al.*, (2002b) screened ruling mulberry varieties *S 36, S 34, S 13, K 2*
and *V 1* for their tolerance to tukra, and stated that *S 36* is highly susceptible and
the multiplication of mealy bug was more on V1 variety. It is clear from above studies that tukra symptoms and mealy bug population varies with varieties.

Biological control processes involve interactions between plants and organisms of the third trophic level (Debach, 1964 and Hoy and Herzog, 1985). A few studies have examined the effects of plant physiology and plant allelochemicals on the biology of parasitoids (Boethel and Eikenbery, 1986). Host plant resistance is usually considered compatible with biological control strategies (Dhaliwal et al., 2005). The morphological, physical, physiological and chemical characteristic of the host plant interact with the parasitoids of the insects by influencing their host seeking ability (Price, 1983; Price 1986) and affecting the efficiency with which they locate and utilize the host (Prokopy, 1983).

Souissi and Ru (1998) stated that the host plant varieties of the cassava mealy bug, *P. manihoti* highly influenced the biological characteristics of its parasitoid *Apoanagyrus lopezi*. Gelman et al., (2005) explained the interaction between host and the parasitoid relating to penetrations of the whitefly *Bemisia tabaci* by the parasitoid wasp, *Eretmocerus mundus*.

**Influence of leaf characters on tritrophic relations**

Biochemical contents of mulberry leaves play an important role in successful silkworm rearing (Aftabahmed, 1998). Bose and Bindroo, (2001) reported that all the mulberry cultivars vary in their nutritional constitution. The
biochemical content of mulberry leaves influence the pest incidence of the plant. Rath and Misra (1998) stated that total amino acids, reducing sugars, protein and chlorophyll had a negative relationship and total sugars and non reducing sugars had a positive relationship with insect resistance of plant.

Based on the biochemical content, the mulberry varieties responded differently to tukra infestation some are affected severely, others moderately and certain others least. The chloroplast content, total soluble proteins, sugars and total free amino acids of the tukra affected leaves varied with varieties (Babu et al., 1994).

Apart from biochemical content, plant morphological features may either enhance or reduce natural enemy activity (Hare, 2002). The plant pubescence (i.e., plant trichomes) interferes with the movement of natural enemies and this often reduces their effectiveness (Kauffman and Kennedy, 1989). VanLenteren and De poniti (1991) reported that this reduced walking speed of the natural enemies help them to search more thoroughly. The presence of wax on leaf surface and increased complexity of leaf shape also interfere with the foraging efficiency of some predators and parasitoids (Andow and Prokrym, 1990). Heidari (1999) stated that the size of the predator and type of trichomes have a marked influence on the level of control of Pseudococcus viburni (Signoret). Plant characteristics such as leaf hairiness are important for the movement and attachment of insects. Trichomes are epidermal appendages. Trichomes affect
the insect behavior by providing a barrier that prevents small arthropods from landing on plant surface, movement and feeding (Goertzen and Small, 1993). In some plants trichome helps arthropods movement. Butler et al., (1991) found that the leaf hopper population declined while white fly population increased as the number of trichomes increased in cotton.

Some natural enemies respond to the odours of host plants. Souissi et al., (1998) reported that the endoparasitoid, A. lopezi of P. manihoti were attracted to P. manihoti infested cassava plants. The olfactometer studies revealed that P. manihoti infested cassava plants were the major sources of volatiles that attracted female parasitoids. The presence of prey on the host enhanced the olfaction of C. montrouzieri (Kotikal and Sengonca, 1999). Olfactometer studies conducted by Buitenhuis (2005) revealed that olfactory cues are probably not essential cues for hyper parasitoid females. Souissi (1999) reported that the parasitoids did not discriminate between cassava cultivars infested by P. manihoti.

Diversity of Insects and their influence

Diversity is the hallmark of life on earth and the reason for its continued existence. Biodiversity is the richness and variety of living organisms in the ecological complexes in which they occur. Throughout the world, human communities have played a central role in shaping nature's diversity and its associated functions. Biological diversity has contributed in many ways to the development of human culture, and mankind has in turn influenced biological
diversity. There are about 1.4 million different species of living organism existing in this world, 7,50,000 insects, 41,000 vertebrates and 2,70,000 plant species (Paul et al., 2005).

Over half of all multi-cellular animal species are insects. Therefore they play dominant vital roles in the functioning of ecosystem. Insects are extremely diverse and important to ecosystem. The pervasive ecological importance of this great variety of insects makes them valuable to assess disturbance or environmental impacts of various kinds (Lehmkuhl et al., 1984).

Insects are very sensitive to ecosystems and their degradation provides a persuasive argument for using appropriate insect taxa as indicators of biodiversity. Monitoring key insect groups can define ecosystem stability and signal actual or potential shifts in productivity, desertification, nutrient cycling, and other changes.

Today this diversity of life is threatened by human activities, although the exact rate of species loss is difficult to ascertain and species loss is only one aspect of the profound transformation of the terrestrial landscape that is presently taking place, brought about by the growth of human population and their economic activities (Solbrig, 1991). Lawton (1998) showed a clear evidence of a reduction in ecosystem process with declining species richness within any one site. Studies on biodiversity provide both opportunities and challenges for knowing how ecological communities are affected by human activities and
environmental interventions. Uthamasamy and Kannan (2006) explained that biodiversity studies are important to effect corrective measures.

Intensively managed agro-ecosystems have long been considered unnatural and monotonous (Wood & Lenne, 1999). Therefore research on pattern and processes maintaining biodiversity in the landscape has focused on species rich natural ecosystems such as wetlands, dry meadows and woodlands (Safford et al., 2001). Arx et al., (2002) stated that agro ecosystems have long been viewed as sites of low biodiversity and their importance for landscape level density is now increasingly recognized.

In agricultural systems natural renewal processes such as nutrient recycling, control of microclimate, regulation of local hydrological processes, regulation of the abundance of undesirable organisms and detoxification of noxious chemicals are largely biological processes and therefore aided by biodiversity (Altieri, 1994). Many traditional farming systems have utilized biodiversity. Since the development of industrialized farming systems, during the “Green Revolution”, ecologically sustainable polyculture have been replaced with large input dependent monocultures. Monocultures can interrupt the self-regulating characteristics of natural communities, like pest control and nutrient cycling, and consequently can become dependent of inputs. Mulberry is extensively grown as monocultures by over exploiting the natural resources and excessively chemicalised (Jayaraj, 2006). In effect, biodiversity’s role in
agroecosystem processes has been replaced with human inputs in modern agricultural systems. When plant communities are manipulated for human use they become more susceptible to insect pests. The self-regulating characteristics of natural communities, like pest control and nutrient cycling, are lost when ecosystem interactions are disrupted by human modification (Altieri, 1999). However, the self-regulating characteristics of natural communities can be restored or repaid by addition of biodiversity (Altieri, 1994).

In addition, insects embody the majority of the links in the community food chain. The multitrophic interactions modify competitive environments and play critical roles in the maintenance of biological diversity of the community (Tscharntke and Hawkins, 2002). The construction of food webs describing the patterns of trophic linkages between insects in a community and manipulation of trophic insect communities is needed to understand the dynamic process underlying insect biodiversity (Godfray et al., 1999).

Organic agricultural systems increase biodiversity (Elsen, 2000). Naito (2000) explained that insect diversity in agroecosystems can be increased by cultivating trap crops. *Hibiscus cannabinus* was shown to be suitable as a trap crop for *Maconellicoccus hirsutus* infesting mulberry (Gowda and Manjunath, 1998). Kanya *et al.*, (2004) found out that the diversity of alternate hosts of maize stem borer declined heavily from 100 per cent to less than 8 per cent when stem borer resistant maize varieties were cultivated.
An agroecosystems which is free from chemical pesticides harbours rich arthropod community, including different kinds of natural enemies and their abundance is sometimes greater than the pests (Ignacimuthu, 2005). Most studies showed that the application of pesticides affected not only the target taxa, but also induced massive mortality of non target taxa and caused an overall decrease in species richness (Teodorescu and Cogalniceanu, 2005). Ellsbury (1998) reported that reduced chemical inputs encouraged greater abundance and diversity of beneficial carabids than in the high input plots without the loss of yield seen in the low input plots. Biodiversity can improve the natural regulation of pests in agroecosystem.

Impact of biotic and abiotic factors on tritrophic relations

Saxena (1996) stated that the combinations of environmental factors, both biotic and abiotic, determine the distribution and abundance of species. Nayar and Ananthakrishnan (1981) found that no particular environmental factors constantly keeps a proportion of any population down or these factors alone cannot maintain an average density balance over long periods of time. In other words the birth and death rates may come about both by genetic and environmental effects.

The occurrence, abundance and incidence of mulberry pests are expected to be influenced by both biotic factors like parasitoids, predators and pathogens, and abiotic factors such as temperature, relative humidity, rainfall, number of
rainy days, sunshine, photoperiod, soil moisture, wind velocity, agronomical practices etc. (Manjunath, 2003). The variation in temperature not only governs the rate at which the living organisms grow but also play an important part in influencing animal behaviour. The effects of temperature change are seldom exerted alone but usually act in combination with one or more other physical factors (Dowdeswell, 1984). Manjunath et al., (1993) reported that the incidence of tukra also varies with seasons.

Odum (1983) reported that temperature rhythms along with rhythms of light, moisture, tides largely control the seasonal and daily activities of plants and animals. He also stated that distribution of rainfall over the year is an extremely important limiting factor for organisms. Humidity along with temperature and light helps to regulate the activities of organisms and limit their distribution. According to Aswathi (1997) every insect species has an optimum humidity value in which it lives well, above or below this value, the result will be detrimental to the insect’s life. It is also explained that as there is no internal regulation of body temperature in insect the rate of chemical processes in their metabolism are influenced directly by the temperature, either speeded up by warmth or delayed by cold. The metabolic rate as measured by oxygen consumption increases with temperature up to an optimum (Chapman, 1982).

Ali (1995) reported that temperature range of 25°C to 28°C and cloudy weather are favourable for the growth and multiplication of M. hirsutus. The
incidence of 'tukra' on mulberry was greatest during the summer and monsoon periods when the temperature was above 30°C and the relative humidity was above 70 per cent in West Bengal (Rao et al., 1993). Chong et al., (2003) failed to establish colonies of Madeira mealy bug, *Phenacoccus madeirensis* Green between 30°C and 40°C. Mani and Thontadarya (1987) found that maximum temperature showed a positive correlation with *M. hirsutus* population while the relative humidity showed negative correlation in grapes. They also observed a high density dependent relationship between *M. hirsutus* and its parasitoid *A. dactylopii*.

Jalali et al., (1999) studied the effect of temperature on the development of *C. montrouzieri* and found that a significant relationship existed with temperature. *C. montrouzieri* are adversely affected by low temperature (Mani, 1988). Sagarra et al., (2000a) reported that lifetime fecundity and reproductive time were significantly affected by temperature and photoperiod conditions. Development of the encyrtid parasitoid *A. dactylopii* was completed in temperature regimes ranging from 20 to 35°C, but neither sex emerged as adults at 15 and 40°C. The development time of males and females decreased from 32.75 to 10 days, and from 34.50 to 11.75 days, respectively, as the temperature increased from 20 to 35°C. Progeny production increased with increase in temperature, reaching a maximum of 182 at 30°C. The sex ratio was altered considerably by different temperatures.
Integrated pest management

Integrated pest management (IPM) is an approach to pest management that uses a combination of several control methods that are both cheap for the farmer and sustainable which includes biological control by conserving and encouraging natural enemies, by changing the crop environment, by changing the cropping practices, by augmenting natural enemies population, and introducing new natural enemies. IPM also includes cultural control viz crop rotation, adjusting pruning dates, ploughing, inter cropping, trap cropping, cover cropping, crop hygiene and chemical control with environmentaly safer pesticides.

Reddy and Seetharama (1997) developed an integrated management of mealybugs in coffee including the use of C. montrouzieri (predator) and L. dactylopii (parasitoid). Integrated control measures, included the control of Formicids with quinalphos, parathion or malathion, destruction of formicid nests, removal and destruction of weeds harbouring the pseudococcids.