CHAPTER ONE

General Introduction

1.1 Background information

Horticulture is recognized for its potential to become one of the major sources of income generation for both small and large-scale farmers in Kenya and Tanzania; creating job opportunities and improving diet by providing essential micronutrients and vitamins (FAO, 2004; HCA, 2010). Therefore, attention on horticulture had been accorded high priority in national development plans of most of the countries in East Africa over the last 25 years. Among the horticultural products grown in Kenya and Tanzania; mango, *Mangifera indica* Linnaeus (Anacardiaceae) is among the most widely grown tropical fruit and over 80 % of the produce from East and West Africa comes from smallholders for both domestic urban (Figure 1.1) and export markets (Figure 1.2) of which the European Union (EU) is the major export destination (ICIPE, 2006). Mangoes play an integral part in rural household lives not only by being rich nutrient source but also serving as a common good that is consumed casually. In Tanzania, Kenya and Malawi mango production is consumed locally contributing to food security. In Africa, particularly in rural areas mango serves principally as a complementary food to populations during the dry-season when staple crops are not produced and food reserves have dwindled (Figure 1.3). This crop provided the most freely available fruit energy and vitamin A and C sources, especially valuable for children in a part of the world where up to 20% of infants die before the age of five (Moore, 2004). Overall, mango plays an important role in food security and nutritional quality (i.e., rich source of vitamin A & C, fibre and potassium, and provide more of the anti-oxidant beta-carotene than any other fruit), and in poverty alleviation.

Figure 1. 1: Smallholder farmer selling mangoes in the city streets of Dar es Salaam

Figure 1. 2: Employees of a mango-packing plant prepare mongoes for export.

Figure 1. 3: Children in a rural village of Zimbabwe consuming mango as a complementary food during the dry-season as staple food reserves dwindle

This locally grown fruit is gaining recognition as an important source of income and foreign exchange; however, increased production in tropical sub-Saharan Africa is limited by many biotic and abiotic contraints. The major biotic constraints are limited access to markets, unavailability of planting materials, poor rural road infrastructure, inadequate air freight transport services for exports, inadequate availabilty and high cost of inputs, shortage of skilled technical expertise, unreliable electricity supplies hence effect on production and inability to comply with various international standards (Wessel, 1997; RTA, 2008). While among the biotic factors, heavy infestation by a range of pests is the most important. Mango mealybug species of the genus *Rastrococcus* are among one of the most destructive pests on mango in Africa, which in addition to other invasive devastating pests such as fruitflies hinder the mango sector from realizing its full potential in the sub-region by posing serious threat to the exploitation of foreign markets, as such helped in jeopardizing the lucrative trade in fresh fruits from the region.

Among the mealybug pest in Africa, *R. invadens* (Figure 1.4) and *R. iceryoides* (Figure 1.5) are regarded as the two most important exotic mealybug species native to Southern Asia that commonly colonize mango (Williams, 2004). *Rastrococcus invadens* Williams (Hemiptera: Pseudococcidae) was first detected in the 1980s along the coast regions of Benin and Togo (Williams, 1989), where it rapidly spread by the mid-1990s and was soon present in several other countries of West and Central Africa namely Sierra Leone, Côte d'Ivoire, Ghana, Nigeria, Cameroon, Gabon, Congo, Burkina Faso, Mali and the Democratic Republic of Congo (Moussa and Matile-Ferrero, 1988; Boussienguent and Herren, 1992; Agounkè et al., 1988). It's continued spread threatened fruit production in the neighbouring countries infesting a wide range of cultivated plants particularly mango, citrus, breadfruit [*Artocarpus altilis* (Parkinson) Fosberg], guava (*Psidium guajava* Linnaeus) and banana (*Musa* spp.), and ornamentals including Oleander (*Nerium oleander* Linnaeus), frangipani and roses (*Rosa* spp.) as well as several other wild host plants (Agounkè et al., 1988; Biassangama et al., 1991). Consequently, it represented a new major threat to Africa's huge potential for commercial horticulture necessary for both the export and domestic markets because of its devastating effects. For example, in Côte d'Ivoire, *R. invadens* appeared in 1989 at the eastern border of the country and, in less than four years became a major constraint to fruit production nation-wide (Hala et al., 2004). By 1996 the mango mealybug had reached the northern region, the main area for export mango production. It was shown that 53% of mango yield losses occurred as the result of *R. invadens* infestations in Korogho-Lataha research station. When yield losses reached 100% in some farms, farmers frequently responded by cutting down and burning of all infested trees in the orchards or sprayed with synthetic chemicals, which showed that the presence of *R. invadens* caused a degree of panic in growers (Agounké et al., 1988 and Vögele et al., 1991). On average, the infestation rates reached 82, 36 and 11% respectively in the cities, villages and orchards. Losses of mango yield attributed to *R. invadens* infestation in Côte d'Ivoire varied from 53 - 100% reduction of total production depending on the variety, the period of harvest, the site of the orchard and the region (Hala et al., 2004; Hauled, 2001). In Ghana, yield losses of up to 80% of mango yield due to *R. invadens* have been reported (Entomological Society of Nigeria, 1991).

Several authors also reported significant reduction in weight and size of fresh mango fruits in Nigeria, Togo and Benin (Ivbijaro and Udensi, 1988; Ivbijaro et al., 1991, Tobih et al., 2002). The insect affected the morphology and physiology of infested trees causing delays in flowering, fall of spikes and leaves and slowing the emission of new branches. The value of mango shipments rejected at European ports because of *R. invadens* infestations reached 200 million francs CFA in 2001 (AU, 2009). In Guinea *R. invadens* was first observed in 2000 and later confirmed by the International Institute for Tropical Agriculture (IITA). Initially localized in one region, the pest rapidly infested the entire country with heavy infestations levels causing a negative economic impact on producers and traders of this commodity. Although the rates of infestations were most important in urban areas than in orchards, the economic and social strain on farmers was greater given the importance of the revenue of mango production, trade and consumption on farmers' income and welfare.

Figure 1. 4: *Rastrococcis invadens* on the abaxial surface of a leaf

Figure 1. 5: *Rastrococcus iceryoides* on the abaxial surface of a leaf

Worldwide, mealybugs constitute one of the major threats to horticultural production, causing heavy pre-harvest and post-harvest losses and curtailing expansion of both domestic and international trade of fruits (Osman and Chettanachitara, 1989). Mealybugs are phytosanitary pests in some export markets (USA, Japan) and if found on fruit destined for these markets can result in rejection of the consignment or rerouting or sold locally with significant economic implications as this could seriously jeopardize the viability or place these important markets at risk for the future (Pieterse et al., 2010). In the tropics, the problem is aggravated by the prevailing humid warm climate, which is conducive for overlapping fruiting patterns, resulting in overlapping generations of mealybug populations and the potential for year round infestation, though at varying degree of severity. Other than *R. invadens*, which received attention because of its pest status, *R. iceryoides* is probably the best-known of the genus (Moore, 2004). Therefore, the arrival of the alien *R. iceryoides* on the continent will further aggravate this problem in East Africa where it is localized.

In Kenya and Tanzania, where *R. iceryoides* is widely distributed across several agroecological zones, it has become a major target for insecticidal sprays on mango, in addition to pruning and burning of infested plant parts (C. Tanga, unpub.; Willink and Moore, 1988). Apart from health and environmental hazards caused by chemical pesticides, pesticide applications do not generally provide adequate control for mealybugs in the long-term owing to their cryptic behavior, their typical waxy body cover, and clumped spatial distribution pattern (Franco, 2009). The eggs of *R. iceryoides* are laid into an ovisac made up of a knotted mass of long waxy filaments, which also prevents penetration of water-based sprays. It is almost impossible to have a spraying program that can bear the cost and cope with the practicalities of treating the whole range of infested plants in an affected area (Sagarra and Peterkin, 1999). Moreover, repeated insecticide use, especially broad-spectrum chemicals has been reported to adversely impacts on mealybug natural enemies (Walton and Pringle, 1999). However, extensive use of these chemicals has also favoured insecticide resistance in mealybug (Flaherty et al., 1982; Myburgh and Siebert, 1964) and has caused the use of some chemicals to be unsustainable due to heightened concerns over health and environmental impact. For example, many of these products are increasingly unacceptable because of their human toxicity and low selectivity; some are no longer available and others are targeted for reduction under national programs and regulations for sustainable use of pesticides, in light of their risk or hazard assessments (Charles et al., 2006; Franco et al., 2004b; Walton et al., 2006). Furthermore, these chemicals are expensive to horticultural farmers in Africa who mainly practice subsistence farming. These setbacks motivated the search for alternative mealybug control strategies that are more environmental benign. For example, *R. invadens* was successfully brought under control by two parasitoid wasps, *Gyranusoïdea tebygi* Noyes (Hymenoptera: Encyrtidae) and *Anagyrus mangicola* Noyes (Hymenoptera: Encyrtidae) by the end of 1990s (Bokonon-Ganta et al., 2002). The parasitoids were found in India and *G. tebigy* was first introduced in Togo in 1987 by the CAB International Institute of Biological Control in a project sponsored by the Deutsche Gesellschaft für Teschnische Zusammenarbeit (GTZ) and the Food and Agriculture Organization (FAO) (Agounkè et al., 1989). In Benin, a survey among mango producer over a large area estimated that the biological control program allowed farmers to gain on average US$ 328 annually. This amounted to an estimated net yearly gain of $US 50 million for the whole country when extrapolated to all farmers of Benin (Bokonon-Ganta et al., 2001). Unfortunately this biological control programme was discontinued while the pest is invading new areas.

Compared with *R. invadens*, very little is known with regard to the bioecology of *R. iceryoides*. The management of *R. iceryoides* will also require various sustainable methods of which biological control with natural enemies is most recommended and although several natural enemies are known to attack *R. iceryoides* in its aboriginal home in Southern Asia, none have been introduced so far into Africa. It is based on this background that the current research was developed and seeks to assess the geographical distribution, abundance, host plant-relationships and associated natural enemies of this exotic pest giving its rising economic importance, which are major precondition to effective management of the pest. Therefore, *R. iceryoides* being an alien species is an excellent candidate for classical biological control. The immediate beneficiaries of this research will be the smallholder mango growers in Africa particularly in Kenya and Tanzania. Smallholders will benefit from improved increased production and access to export markets due to high quality mango products.

1.2 Justification

Since the first report of *R. iceryoides* in East Africa (mainly Tanzania and Kenya), the mealybug has become established in the northern part of Malawi (Williams, 1989; Luhanga and Gwinner, 1993; CABI, 2000) where it has remained as a major pest of mango causing alarming yield losses and potentially poses a threat to numerous other horticultural products. Given the fact that most mealybug species have the ability to disperse over long distances, there is a great likelihood that the pest may spread further. The informal movement of plant materials between very porous African borders by many travelers and/or major agricultural projects such as development of horticulture or re-afforestation programs; and general lack of strict quarantine regulations may also facilitate the spread of this pest to new areas. Also, the regional integration of several African countries into Customs Unions allows free movement of all kinds of agricultural commodities that further increases the risk of spread.

Rastrococcus iceryoides is a pest that is new on mango in Africa and was only described in the 1989 (Williams, 1989). There is currently a paucity of information on various aspects of its bioecology that might aid in the management of the pest. As a result of *R. iceryoides*' exotic origin, polyphagy, rapid rate of reproduction and spread, biological control with natural enemies remains the most recommended and cost-effective option. This is technically possible as demonstrated in West Africa for *R. invadens*, which is a member of the same genus as *R. iceryoides*, though at tremendous cost (Agricola et al., 1989; Matokot et al., 1992; Neuenschwander et al., 1994, Boavida et al., 1995). However, the scale of distribution of *R. iceryoides* at present, poor quarantine and limited knowledge of potential cultivated and wild hosts and lack of resources in Africa suggests that suppression may be difficult, if not impossible. The most practical strategy, therefore, is the development of appropriate management measures that are suited to the local conditions in Africa and sustainable. Therefore, as part of the ongoing efforts to manage this pest, the African Fruit Fly Program of *icipe* is developing and testing a range of integrated pest management (IPM) technologies that are adaptable to the region. However, such strategies can best be utilized if the bioecology of the pest is well documented.

Therefore, this study aims at understanding the bioecology of *R. iceryoides* as part of a wider strategy to develop sustainable management strategies for the pest. The host plants range of *R. iceryoides* is documented and the suitability of different host plants to the pest as relevant to the development of mass rearing procedures and efficacy of its primary indigenous parasitoid (*Anagyrus pseudococci* Girault) has been established. Population dynamics studies have been undertaken. Considering the fact that this pest is alien to the African continent the likelihood of identifying efficient natural enemies within Africa is slim. Therefore, the study also explored for co-evolved natural enemies of *R. iceryoides* in its putative aboriginal home, India as part of a wider long-term sustainable program for the management of *R. iceryoides*. Lastly, the role of *Oecophylla longinoda* in the biological control of *R. iceryoides* by *A. pseudococci* has been determined.

1.3 Hypotheses

The following hypotheses were tested;

- *Rastrococcus iceryoides* is the most polyphagous, widespread and devastating mealybug of mango in Tanzania and Kenya, with no effective indigenous natural enemies.
- There is a huge diversity of effective natural enemy complex in the aboriginal home of the pest, India.

1.4 Objectives of the study

1.4.1 General objective

The overall objective of this study is to determine the bio-ecology of *R. iceryoides*, assess the role of indigenous natural enemies in suppressing the pest; and explore for natural enemies in its aboriginal home for introduction and release in target African countries.

1.4.2 Specific objectives

The following specific objectives were addressed;

- Assess the distribution, host plant relationships of *R. iceryoides* and its associated natural enemies in Kenya and Tanzania
- To assess the role of host plants on the development, survivorship and reproduction of *R. iceryoides*
- To assess the effects of host plants on the biological parameters of *R. iceryoides* and its key parasitoid, *A. pseudococci* under laboratory condition
- To assess the interaction between *Oecophylla longinoda*, *R. iceryoides* and *A. pseudococci* under laboratory conditions
- To establish the seasonal and annual dynamics of *R. iceryoides* and its associated natural enemies in two major mango growing areas in the Coast region of Tanzania.
- To explore for natural enemies of *R. iceryoides* in its aboriginal home and establish a climate matching to guide introduction of promising parasitoids into Africa.

CHAPTER TWO

Literature Review

2.1 MANGO

2.1.1 Origin and Distribution

Mango, *Mangifera indica L.,* one of the most celebrated of tropical fruits, is a member of the family Anacardiaceae–notorious for embracing a number of highly poisonous plants (Morton, 1987). Native to southern Asia, especially eastern India, Burma, and the Andaman Islands, mango has been cultivated, praised and even revered in its homeland since ancient times (Morton, 1987). Buddhist monks are believed to have taken the mango on voyages to Malaysia and eastern Asia in the 4th and 5th Centuries B.C. The Persians are said to have carried it to East Africa about the 10th Century A.D. (Morton, 1987). It was commonly grown in the East Indies before the earliest visits of the Portuguese who apparently introduced it to West Africa early in the 16th Century and also into Brazil (Morton, 1987). After becoming established in Brazil, the mango was carried to the West Indies, being first planted in Barbados about 1742 and later in the Dominican Republic. It reached Jamaica about 1782 and, early in the 19th Century, reached Mexico from the Philippines and the West Indies (Morton, 1987). The original wild mangoes were small fruits with scant, fibrous flesh, and it is believed that natural hybridization has taken place between *M. indica* and *M. sylvatica* (Roxb.) in Southeast Asia (Morton, 1987). Selection for higher quality has been carried on for 4,000 to 6,000 years and vegetative propagation for 400 years (Morton, 1987). Important mango varieties include Kent, Keitt, Tommy Atkins mango, Haden mango and Ataulfo mango (www.freshmangos.com).

2.1.2 Mango production and international trade

A large number of mango varieties are commercially grown in different parts of the world, some with determinate and others with indeterminate growth pattern. Within international trade, fresh mango is one of the main products. It possesses a fifth place on total fruit crop production globally (Tharanathan et al., 2006), accounting for over one-third of the worldwide production on tropical fruits (Maneepun and Yunchalad, 2004). Mangoes are grown on all continents (Galán Saúco, 2004), with at least 87 countries reported to be involved in mango production by the year 2000 (Galán Saúco, 2004; Tharanathan et al., 2006). Around 25 million tons were grown in 2000 (Galán Saúco, 2002; Galán Saúco, 2004; Maneepun and Yunchalad, 2004) of which three-quarters in Asian countries. India is by far world leader with almost half of the global mango production, however exports only a very small amount of this. Mexico, Pakistan and the Philippines are the most important exporters for fresh mangoes with 41%, 7.6% and 7.8% of the global supply respectively (Galán Saúco, 2002; Galán Saúco, 2004). International trade in mango has risen significantly by the end of the twentieth century (Galán Saúco, 2004), enabled by improved post-harvest techniques (Maneepun and Yunchalad, 2004). Over a million tons were traded in 2006 (FAOSTAT). Large markets for fresh produce are the EU, North-America and Asia (Galán Saúco, 2002; Galán Saúco, 2004).

In Africa, Nigeria produces the largest amount of mangoes on the continent and occupies the 8th position in the world ranking of mango producing countries as at 2002, producing 730,000 metric tonnes annually (FAO stat cited by Yusuf and Salau, 2007) followed by Kenya in the 9th position but ranks second in terms of exports after South Africa. Common varieties grown in Kenya and Tanzania include Apple, Baribo, Dodo, Haden, Keitt, Kent, Van Dyke, Tommy Atkins, Ngowe, Sensation and local landraces. Apple and Ngowe varieties have high demand by the export market sub-sector. Other major mango producing countries on the continent include Sudan, Egypt, Madagascar and Tanzania (Yusuf and Salau, 2007). According to data presented at the FAO Inter-Governmental Sub-Group on tropical fruits, mango exports from Africa were estimated at 35-40,000 tons annually and worth over USD 42 million annually (ICIPE, 2006; Lux et al., 2003). The EU is the largest destination market for mangoes exported from Africa, followed by the Middle East (Lux et al., 2003). Both fresh and processed mango are been exported to the European countries with France as the major importer followed by the United States. Both account for 70% of the world mango import (Yusuf and Salau, 2007). In East and West Africa, over 80% of the produce comes from smallholders for both domestic and urban export markets (ICIPE, 2006).

Despite the substantial increase in mango exports in recent years, the share of all African suppliers to European markets remains below 20% (ICIPE, 2006) as several factors constrain mango production, among which insect pests are regarded as among the most important (Acland, 1971; Griesbach, 1992; Joubert et al., 2000; Varela, et al., 2006; ICIPE, 2006). Heavy losses are also being incurred by exporters whose mango shipments infested with these quarantine pests are intercepted and destroyed at the entry of EU markets because when insect pests are encountered on fruit, they must be identified before the fruit can be shipped. Until such time as identification can be made, the fruit is held in cold storage at a large cost to both the producer and the shipper.

If the insect dies or the specimens are damaged, no identification can be made; therefore the consignment must be destroyed or sold locally at a reduced rate. This greatly affects the revenue and reduces the profits of the smallholder grower and the traders and contributes to high mango production cost. For example, mango exports from some West African countries have even been banned from entering EU markets and the United States due to insect pest damage (Van Mele et. al., 2007) with substantial impact on producers' income reported with grave consequences on local trade, food security and export potential.

2.2 Mealybug

2.2.1 Taxonomic position, bioecology, host range and distribution of *R. iceryoides*

Rastrococcus iceryoides belongs to the class Insecta, order Hemiptera, suborder Sternorrhyncha, superfamily Coccoidea and to the family Pseudococcidae. It is the type species of the genus *Rastrococcus* and was first described by Green in 1908. Ferris (1954) gave detailed descriptions and illustrations. In his revision of the genus *Rastrococcus*, Williams (1989) notes that this species possesses major characters not found in any of the other 22 species of the genus and hence has assigned it to a separate species group. Narasimham and Chacko (1988) observed and described four main types of variation in colour and pattern of wax on the ovisac. These varieties co-exist on mangoes and retain these characters when bred on pumpkin. Williams (1989), however, notes that slide preparations of these specimens appear to be identical and, at present, there is no suggestion that they represent different species. Validation characters include the presence of an anterior ostioles; cerarii with more than 5 truncate setae; cerariion anterior thorax and head coalesced; with long dorsal setae adjacent to anal ring; antennae 9-segmented; quinquelocular pores present on venter; denticle on claw. Other species in the genus *Rastrococcus* lack anterior ostioles and have short setae near the anal ring.

Rawat and Jakhmola (1970) and Pramanik and Ghose (1991) have given an account of the bionomics of *R. iceryoides* while Dikshith (1966) studied the cytology. The adult male has one pair of wings, well-developed limbs, lacks mouthparts and lives only a few days. The female lays eggs only after fertilization. The pre-oviposition period lasts 7-8.5 days and the oviposition periods last for 5.7-7.3 days. About 450-585 eggs are laid in a white, waxy ovisac. On potato sprouts, fecundity averaged 807.8 eggs/female and the oviposition period averaged 18.2 days. However, starvation reduced the fecundity by 82.18% and the oviposition period by 58.24%. The average incubation period was 6.6 days. Female and male nymphs moult three and four times, respectively, to become adults. The average duration of post-embryonic development was 20.4-31 days in females and 18-26 days in males. On potato sprouts, the nymphal period is reported as 24.77 days in females and 25.41 days in males.

Rastrococcus iceryoides is one of the most polyphagous species of the genus *Rastrococcus*, occurring on plants belonging to diverse botanical families. Ramachandran and Ayyar (1934) have noted it on 15 host plants belonging to eight botanical families. Ali (1970) has listed over 40 plants as hosts of *R. iceryoides*. Narasimham and Sankaran (1985) note 17 host plants belonging to 10 botanical families. Williams (1989) and Ben-Dov (1994) have studied specimens of *R. iceryoides* from over 65 different host plants from 31 plant families. Both adult and immature stages are highly pestiferous and have a strong preference for mango. The most frequent host plants are: *M. indica*, *Gossypium hirsutum* L. (Bourbon cotton), Citrus, *Citrus aurantiifolia* L. (lime), Coffea (coffee), *Coffea canephora* Pierre (Congo coffee tree), *Coffea arabica* L. (coffee (arabica)), *Theobroma cacao* L. (cocoa), *Albizia lebbeck* (L.) Benth (Indian siris), *Gossypium* sp. (cotton) (Williams, 1989).

Williams (1989) noted that *R. iceryoides* is known throughout most of southern Asia and is one of the most widespread species of the genus *Rastrococcus*. It is also considered one of the most devastating pests of mango throughout its distribution range. It distribution range encompasses the whole of Indian, Bangladesh, China, Hong Kong, Singapore, Sri Lanka and Malaysia and has extended its range to Africa, mostly Tanzania, Kenya and Malawi (Figure 2.1), where it was probably introduced at the beginning of the twentieth century. The distribution map includes records based on specimens of *R. iceryoides* from the collection in the Natural History Museum (London, UK).

Figure 2. 1: Global distribution of *R. iceryoides* (Williams 1989).

2.2.2 The Origin of Mealybug Pest Status

Similarly to other insect pests, mealybugs have diverse origins, including endemics, immigrants, and mutants (Kim, 1993). An indigenous species may become a serious pest: when a susceptible crop species is introduced into the area; following environmental disturbance; or as a result of stress conditions. Invasive mealybug species may attain pest status as soon as they successfully colonize a new territory, and impact negatively crop yield, which may happen when they encounter a susceptible host, either local or exotic. The mango mealybug, *R. invadens*, is an introduced pest in most mango-growing areas of West and Central Africa. Infestation by *R. invadens* weakens young mango seedlings and severely affects the growth of both fruit-bearing (cultivated) and wild (non-cultivated) trees; the damage is mainly due to leaves, twigs and fruit infestation. Three major causes can lead to mealybug outbreaks:

Firstly, invasion by an exotic mealybug species, which immediately leads to severe outbreaks, is believed to be mainly driven by the combination of host susceptibility and absence of natural enemies in the invaded region (Ben-Dov 1994; Blumberg et al., 1999; Muniappan et al., 2006; Nakahira and Arakawa 2006; Roltsch et al., 2006; Williams and Granara de Willink 1992).

Secondly, the application of non-selective pesticides has been reported to disrupt the biological balance and may lead to resurgence and secondary outbreaks. For example, heavy and damaging outbreaks of *Pseudococcus longispinus* (Targ.) were reported in Israel on avocado plantations bordering cotton fields resulting from disturbances in the biological equilibrium caused by the drifting of insecticides applied from aircraft for the control of cotton pests (Swirski et al., 1980). The mechanisms involved in these two types of outbreaks were discussed by Hardin et al. (1995), and studied by Franco et al. (2004b) with regard to the mealybug pests of citrus. Although the citrus mealybug, *Planococcus citri* (Rossi) is regarded as an occasional pest, it can be extremely damaging and difficult to control. Because it infests the fruit and is often deep within the tree canopy, insecticide applications are often not very effective due to poor coverage. Applications of non-selective insecticides for mealybugs end up aggravating the problem due to the destruction of natural enemies. Among these is a particularly effective parasitoid, *Anagraphus* sp., which has been reported as the primary biological control agent responsible for the apparent "disappearance" of citrus mealybugs in the spring in groves where heavy infestations occurred the previous summer (Franco, 2009).

Thirdly, the effect of environmental factors may also directly and indirectly affect the tritrophic interactions that develop between mealybugs, their host plants and their natural enemies and thereby initiate mealybug outbreaks. Several mechanisms may be involved. Host–plant characteristics may favor or be detrimental to the development, reproduction and survival of mealybugs (Boavida and Neuenschwander, 1995; Calatayud et al., 1994b; Leru and Tertuliano, 1993; Nassar, 2007; Tertuliano et al., 1993; Wysoki et al., 1977; Yang and Sadof, 1995). The resistance mechanisms of the host plant may become involved in both the fixation (antixenosis) and the development of the mealybug (antibiosis) (Tertuliano et al., 1993). Tertuliano and Leru (1992) concluded that the different levels of resistance to the cassava mealybug, *Phenococcus manhioti* (Matile-Ferrero), that were observed in the different varieties of cassava, were not associated with the concentrations of amino acids or sugars, with the ratios between these concentrations, or with the compositions of amino acids obtained from leaf extracts. The identification and assay of cyanogenic and phenolic compounds in the phloem sap of cassava and the honey-dew of the cassava mealybug were carried out by Calatayud et al. (1994a). The best correlation between antibiotic, resistance and secondary compounds analyzed was observed for the rutin contents of infested plants. Yang and Sadof (1995) showed that variegation in *Coleus blumei* (Benth.) could increase the abundance of the citrus mealybug, *P. citri*. Sadof et al. (2003) found that the life history characteristics of *P. citri* on *Coleus blumei* were not correlated with total amino acids and sucrose contents in stem exudates, and were correlated negatively with the proportions of shikimic acid precursors and positively with those of other nonessential amino acids. Host–plant characteristics have also been reported to greatly influence the performance of the natural enemies of mealybugs (Serrano and Lapointe, 2002; Souissi, 1999; Souissi and LeRu, 1997a; Yang and Sadof, 1997).

Water stressed plants has also been reported to favor population increases of mealybug (Calatayud et al., 2002; Gutierrez et al., 1993; Lunderstadt, 1998; Shrewsbury et al., 2004). Mealybug life history parameters may also be influenced by the levels of nitrogen fertilization and leaf nitrogen concentration; high nitrogen concentrations were shown to lead to enhanced performance of the citrus mealybug, *P. citri* (Hogendorp et al., 2006). The antibiotic resistance of two varieties of cassava to the cassava mealybug was observed to increase with the addition of nitrogen (Leru et al., 1994). Survival of immature sugarcane mealybug, *Saccharicoccus sacchari* (Cockerell), increased to a maximum at a soluble nitrogen concentration of 320 mg L^{-1} in sugarcane, and decreased at higher levels, whereas mealybug size increased with increasing nitrogen concentration over the whole tested range (Rae and Jones, 1992).

Weather conditions, especially temperature and relative humidity, are major ecological factors that have been found to severely affect both mealybug and their natural enemies (Chong and Oetting, 2006; Chong et al., 2004, Chong et al., 2005; Daane et al., 2004b; Gutierrez et al., 1993, Gutierrez et al., 2008a; Kontodimas et al., 2004; Nakahira and Arakawa, 2006; Walton and Pringle, 2005).

Encapsulation may adversely affect the degree of biological control exerted by mealybug parasitoids, as it may either prevent the establishment of exotic parasitoids in new regions or reduce parasitoid efficacy (Blumberg, 1997). Also the cryptic behavior of mealybugs and tending of mealybugs by ants may, respectively, originate spatial and temporal refuges from natural enemies. Several other factors can also affect mealybugs' natural enemies; which include intraguild predation and interference (Chong and Oetting, 2007a), and hyperparasitoids (Moore and Cross, 1992), although the latter factor has never been proven to significantly impair biological control of mealybugs.

2.2.3 Economic importance of mealybugs

All mealybug pests are phytophagous and often invasive species with great economic importance around the world. For example in the USA, there are 350 species of mealybug of which approximately 70% of the 66 mealybug species that are considered as pests are invasive (Miller et al., 2002). In New Zealand, most of the known 114 species of mealybugs are found only on native plants. Three cosmopolitan and invasive *Pseudococcus* species are frequently occurring pests of horticultural crops in the country, where they account for more than 99% of the mealybug fauna in orchards and vineyards (Charles, 1993). In Israel, only one among 13 mealybug pests may be considered native (Franco, 2009). In France, scale insects, including mealybugs, represent 31% (Streito and Martinez, 2005) of newly introduced species in recent years, although all mealybug pests on grapevine are native (Sforza, 2008a; Sforza, 2008b).

Rather few narrow host-range plant mealybugs are considered major pests on an international scale, as in the case of the cassava mealybug *Phenacoccus manihoti* (Matile-Ferrero, 1977; Neuenschwander, 2001; Williams and Granara de Willink, 1992; Zeddies et al., 2001). However, the most notorious species are polyphagous and have become serious pests of different crops under different environments. Many of them are cosmopolitan species belonging to the genera *Pseudococcus* and *Planococcus*; they spread between continents through international trade. Several members of the genus *Pseudococcus*, for example, *P. calceolariae* (Maskell), *P. longispinus* (Targioni-Tozzetti), and *P. viburni* (Signoret), are important pests of apple, pear and vineyards in New Zealand (Charles, 1993), whereas around the Mediterranean they are considered mainly as pests of citrus, persimmon and several other subtropical fruit trees (Franco et al., 2004b). The citriculus mealybug, *P. cryptus* Hempel is a major pest of citrus in the east Mediterranean region and it attacks coffee roots in Asia and South America (Ben-Dov, 1994; Blumberg et al., 1999; Williams and Granara de Willink, 1992). Two members of the genus *Planococcus* are among the best known pests of the family: on an international scale, the vine mealybug, *P. ficus* (Signoret) damages mainly vines (Ben-Dov, 1994; Daane et al., 2006a; Gutierrez et al., 2008a; Walton et al., 2004; Zada et al., 2008), whereas the citrus mealybug, *P. citri* (Risso), attacks mainly subtropical fruit trees under Mediterranean climate conditions and ornamental plants in interior landscapes in cooler zones (Ben-Dov, 1994; Franco et al., 2004b).

Polyphagous mealybugs pose a serious threat because of their tendency to adopt new host plants easily. The citrus mealybug has become a key pest in the mint and tarragon industry in Israel and another example that indicates the high economic importance of a polyphagous mealybug is the pink hibiscus mealybug, *Maconellicoccus hirsutus* (Green). This mealybug is indigenous to southern Asia, and actually is considered a potentially serious pest in the United States, because of its extremely broad range of economically important hosts, including citrus, ornamentals, vegetables, and native American flora. It was first reported in the Western Hemisphere in Hawaii in 1984, and later in Grenada in 1994; subsequently it has spread rapidly through the Caribbean islands and to southern California (1999) and Florida (2002). Without control, the economic impact of the hibiscus mealybug to U.S. agriculture was estimated at $750 million per year (Hall et al., 2008; Roltsch et al., 2006; Vitullo et al., 2007; Zhang et al., 2006). The solanum mealybugs, *Phenacoccus solani* Ferris and *P. solenopsis* Tinsley are examples of invasive pests of annual crops; they cause devastating damage to green pepper in Israel and cotton in the Indian sub-continent (Ben-Dov, 2005b; Hodgson et al., 2008; Nakahira and Arakawa, 2006).

Recently, mango infestation in Africa has been reported by two invasive mealybug species of Asian origin, i.e. *R. invadens* and *R. iceryoides* causing serious damage to fruit trees especially mango and citrus (Agounké et al., 1988). The former devastated mango production in West and Central Africa with yields of mango and citrus plummeted, effectively to about zero in areas with longest exposure to the insect. The accounts of yield losses are largely not quantified, but can be estimated to range between 50-80% (Neuenschwander, 2003a). Factors responsible for the lack of statistics on fruit losses caused by this insect pest can be attributed to the traditional nature of horticulture in the regions, which hampers the collection of statistical data as people’s reaction towards *R. invadens* led to control measures such as trimming, and in case of desperation, felling of infested trees as result of general panic generated by the proliferation of the pest.

The damage caused by mealybugs is linked to sap uptake, honeydew secretion and associated sooty mold development, toxin injection and virus transmission, although the presence of the insects may itself lead to economic losses (Franco et al., 2000; Gullan and Martin, 2003; McKenzie, 1967; Panis, 1969). The typical injury includes: (a) leaf and fruit discoloration; (b) defoliation, flower and fruit drop; (c) reduction of fruit growth rate; (d) distortion of leaves, new shoots and fruits; (e) aborted plant shoots; (f) development of cork tissue on fruit peel; (g) soiling of fruits with mealybugs and honeydew, which encourage the development of sooty mould *Capnodium mangiferum* Cooke & Broome (Capnodiaceae) known to also raise the leaf temperature of infected mango seedlings; and (h) reduction of plant vigor (Franco et al., 2000, Franco et al., 2004b; Gullan and Martin, 2003; Hodges and Hodges, 2004; Sagarra et al., 2001). High densities or annually repeated infestations can even kill perennial plants (Hodges and Hodges, 2004; Walton et al., 2004; Walton et al., 2006). Indirect damage can result from trophic interactions between mealybugs and other insect pests that are attracted by honeydew, such as Lepidoptera (Franco et al., 2000; Mittler and Douglas, 2003; Silva and Mexia, 1999b).

Several mealybug species are vectors of viral diseases of various crops: banana (Kubiriba et al., 2001; Thomson et al., 1996; Watson and Kubiriba, 2005), black pepper (Bhat et al., 2003), cocoa (Dufour, 1991; Entwistle and Longworth, 1963; Hall, 1945), grapevine (Cid et al., 2007; Sforza et al., 2003; Tsai et al., 2008; Zorloni et al., 2006), pineapple (Sether and Hu, 2002a; Sether and Hu, 2002b; Sether et al., 2005), rice (Abo and Sy, 1998), and sugarcane (Lockhart et al., 1992). In such cases, mealybugs may be economic pests even at low densities. For example, several mealybug species are responsible for GLRaV-3 (Grapevine LeafRoll associated Virus-3) transmission to grapevine, which has been shown by the strong positive correlations between mealybug numbers and infection levels in the following season. The virus infection was predicted to spread rapidly within the vineyard within the economic impact of GLRaV-3 infection in sensitive varieties exceeding $10,000 per ha annually and profitability was sufficiently affected to justify replanting (Walker et al., 2004).

Mealybugs have also been used as beneficial insects in biological control of weeds. For example, *Hypogeococcus pungens* Granara de Willink was successfully introduced from Argentina into Queensland (Australia) for the control of harrisia cactus (*Eriocereus martinii*

Labouret) and related plants (Williams and Granara de Willink, 1992). Some mealybug species may also be manipulated as beneficial insects in conservation biological control tactics. For example, the cypress mealybug, *P. vovae* (Nasonov), which occurs on cypress trees (*Cupressus* spp.) grown in windbreaks, serves as an alternative host for natural enemies of mealybug pests in surrounding citrus orchards and cocoa plantations (Cox, 1989; Ho and Khoo, 1997; Franco et al., 2004b).

2.2.4 Feeding process

Mealybugs feed by inserting their stylets through the plant tissue to suck up sap from either phloem or mesophyll, or both. Males terminate their feeding towards the end of the second nymphal stage. Generally, stylet penetration is accomplished by secretion of solidified saliva that forms a sheath around the stylets. Similarly to other members of the suborder Sternorrhyncha, which includes scale insects, aphids, psyllids and whiteflies, mealybugs consume a diet containing mainly carbohydrates but also limited amounts of free amino acids and other nitrogen compounds (Franco et al., 2000; Gullan and Martin, 2003; Silva and Mexia, 1999a; Tonkyn and Whitcomb, 1987). Thus, except for sucrose hydrolysis, food digestion is hardly necessary. However, organic compounds in phloem sap need to be concentrated before they can be absorbed, and this occurs in the filter chamber, a specialized component of the digestive system, which enables the direct passage of water from the anterior midgut to the Malpighian tubules, thereby concentrating food in the midgut (Terra and Ferreira, 2003). The residue of ingested phloem sap, after digestion and assimilation in the insect gut, is released from the anus as a sugar-rich material, the honeydew. Up to 90% of the ingested sugars may be egested in this way (Mittler and Douglas, 2003).

2.2.5 Reproductive systems and sex determination

Most mealybug species reproduce sexually, and lay eggs (Gullan and Kosztarab, 1997; Kosztarab and Kozár, 1988). However, some, such as *Phenacoccus solani*, (Nakahira and Arakawa, 2006), *P. parvus* (Marohasy, 2003), and *Ferrisia malvastra* (McDaniel) (Ben-Dov, 2005a), reproduce parthenogenically, and others, for example, *P. longispinus* (Franco et al., 2000), and *Antonina graminis* (Maskell) (Ben-Dov, 2006), are ovoviviparous. Two different genetic systems may be found in mealybugs. The more common corresponds to a particular type of haplodiploidy, known as paternal genome elimination, in which both males and females develop from fertilized eggs; the male develops from a zygote containing one haploid genome from his mother and one haploid genome from his father, but only the maternal genome is transmitted to the offspring via the sperm, because the set of chromosomes of paternal origin becomes heterochromatic and genetically inactive (Normark, 2003; Nur, 1990). Male mealybugs are thus functionally haploid, owing to heterochromatization (parahaploidy) (Bongiorni et al., 2001). The other genetic system is thelytokous parthenogenesis, in which there are no males and therefore no mating occurs (Normark, 2003).

There are no sex chromosomes in mealybugs; sex is probably determined by a functional haploidy/diploidy mechanism, which seems to be dependent on the behavior of a set of chromosomes and not a single chromosome. If heterochromatization of an entire set of chromosomes takes place during the cleavage stage of embryogenesis, the embryo will develop into a male; otherwise it will develop into a female. Spermatogenesis is characterized by inverse meiosis and absence of chromosome pairing and genetic recombination (Khosla et al., 2006; Sánchez, 2008). Recently Sánchez (2008) suggested that the genome of the mother determines the heterochromatization of the inherited paternal chromosomes in mealybug embryos. According to this model, heterochromatization is controlled by a maternal factor, with the maternally derived chromosomes imprinted so that they do not suffer the fate of the male chromosome.

Sex determination in mealybugs, and consequently the sex ratio, is known to be influenced by temperature and the age of the mother (Nelson-Rees, 1960). The effect of the temperature or the age of the mother on the offspring sex ratio is attributed to a change in the ratio between the numbers of oocytes with and without the maternal factor (Sánchez, 2008).

2.2.6 Defence system

Mealybugs developed several different defense mechanisms. Many of the species tend to establish themselves in protected sites, such as cracks and crevices in bark, leaf axils, root crowns, nodes of grass stems, under fruit sepals and within fruit navels, between touching fruits or fruits and leafs, and in tunnels bored by insect larvae in roots and stems (Franco et al., 2000;

Kosztarab and Kozár, 1988). This cryptic behavior of mealybugs may originate a spatial refuge from natural enemies and harsh environmental conditions (Berlinger and Golberg, 1978; Gutierrez et al., 2008a). This type of plant colonization makes mealybugs practically invisible during the latent population phase. However, during outbreaks the population explodes from the refuge and becomes conspicuous.

The waxy secretion is the most common conspicuous trait of the mealybug family. It is a complex system that serves different functions, and which is produced by the epidermal wax glands and transported to the body surface via ducts, pores, and secretory setae of various types (Foldi, 1983; Gullan and Kosztarab, 1997). Zada et al. (2009) found that the main components of the wax of five mealybug species (*P. citri*, *P. ficus*, *P. vovae*, *P. cryptus*, and *N. viridis*) were trialkylglycerols and wax esters. The wax cover is believed to prevent water loss. The hydrophobic property of the wax enables the mealybugs to escape drowning or becoming swamped by water in their typical cryptic sites. The ovisac, which is also a wax secretion, is considered to be an adaptation that protects the offspring from both wet and dry conditions, and that may also provide an attachment to the host plant. Tubular ducts and multilocular disc pores, respectively, produce long hollow and shorter curled filaments, which make up the ovisac and the male cocoon (Cox and Pearce, 1983; Foldi, 1983). The white wax of mealybugs is strongly light reflective, and may reduce desiccation in some cases; the wax also serves to cover the honeydew droplets and to protect the mealybugs from contamination by their own honeydew and defensive exudates (Gullan and Kosztarab, 1997).

The wax cover and the secretion process are involved in mealybug defense against natural enemies. It is hypothesized that the rarity of infestation by pathogens and nematodes is related to the wax shield. Stuart et al. (1997) found varied susceptibility of *Dysmicoccus vaccinii* Miller and Polavarapu to several nematode species; they showed that removal of the waxy coating from the mealybug did not influence their susceptibility to *Heterorhabditis bacteriophora* Poinar. The lateral wax protrusions protect the mealybugs from predators and facilitate spacing of individuals within the colony. The nymphs and adult females of most mealybugs possess two pairs of dorsal ostioles, located between the head and prothorax and on the sixth abdominal segment, that discharge a globule of liquid when the insect is disturbed. This waxy liquid solidifies quickly on contact with air and is believed to have a defensive function

(Eisner and Silberglied, 1988, Gullan and Kosztarab, 1997). It was found, for example, that this discharge negatively affect *Sympherobius fallax* Navas (Neuroptera, Hemerobiidae) larvae (Gillani and Copland, 1999), green lacewings (Neuroptera, Chrysopidae), and the parasitoid *Leptomastidea abnormis* (Girault) (Hymenoptera, Encyrtidae) (Franco, 1999). Ostiolar secretions may have different functions in other mealybug species, for example, the highly developed condition of the dorsal ostioles in obligate ant-attended mealybugs suggests that the released fluid may attract the ants (Gullan and Kosztarab, 1997).

Major parasitism in mealybugs involves members of the wasp family Encyrtidae. The encyrtids are koinobiont endoparasitoids, so that the parasitized mealybug continues to live for a few days, to grow and even to reproduce to some extent. This time gap between parasitization and deterioration of the physiological condition enables the mealybug to confront the immature individual parasitoid by encapsulation. The encapsulation is a common immune defense mechanism that involves the formation of a capsule around the parasitoid egg or larva; it is usually composed of host blood cells and the pigment melanin. The capsule may kill the parasitoid and thus prevent successful parasitism (Blumberg, 1997). Various levels of encapsulation have been shown to occur in different mealybug species, in response to parasitism by encyrtids (Blumberg, 1997; Blumberg et al., 1995; Blumberg et al., 2001; Blumberg and van Driesche, 2001; Chong and Oetting, 2007b; Giordanengo and Nenon, 1990; Sagarra et al., 2000). Conversely, encyrtid parasitoids may use superparasitism as a strategy to overcome the immune response of unsuitable hosts (Blumberg et al., 2001). Besides superparasitism, other factors also affect the frequency of parasitoid encapsulation including: (a) host and parasitoid species; (b) the host's physiological age and condition; (c) the host and parasitoid origins (or strains); (d) the rearing and/or ambient temperature; and (e) the host plant species and stress conditions (Blumberg, 1997; Blumberg et al., 2001; Calatayud et al., 2002).

2.2.7 Host plants

Mealybugs feed on a variety of herbaceous and woody plants, including the angiosperm, gymnosperm and fern families. However, most of the species with known hosts develop on herbaceous plants, especially grasses (Poaceae) and composites (Asteraceae) (Ben-Dov, 2006; Kosztarab and Kozár, 1988).

As expected, information on the host ranges of mealybugs is mainly derived from observations of species of economic importance. Most species are oligophagous or stenophagous (or monophagous) while others are polyphagous (Ben-Dov, 2006; Kosztarab and Kozár, 1988). However, such a characterization is problematic as most of the economically important species are known to be associated with long lists of hosts, and their performance varies widely, ranging from development of high population density, which eventually would kill the host plant, to poor development that renders the survival of the population for several generations questionable. Plant growth conditions may strongly affect the success of the population: under irrigation and fertilization plant species become favorable hosts of mealybugs, whereas in different environments the performance is usually poor. During laboratory studies many of the mealybug pest species easily could be reared on alternative hosts, such as potato sprouts or squashes, which are not colonized by mealybugs in the field. For example, the citrus mealybug has been found on plants from 70 botanical families, 60% of which are characterized as non-woody plants, whereas on the international scale this mealybug is a pest of subtropical and tropical crops, such as citrus (*Citrus* spp.), persimmon (*Diospyros kaki* Thunberg), banana (*Musa paradisiacal* L.), and custard apple (*Annona* spp.), or it damages various types of plant species in interior landscapes, greenhouses in particular. Another example of the apparent contradiction between the long lists of host plants and the narrow ranges of damaged crops is the case of the citriculus mealybug, *P. cryptus*; although this mealybug is known from 35 host plant families (Ben-Dov, 2006), in Israel it causes damage only to citrus trees. Under low pressure of natural enemies, for example, when they spread in new environments, mealybugs are observed on relatively large numbers of host plants, in contrast with the situation when there is effective biological control.

2.2.8 Dispersal

Adult males and newly emerged first-instar nymphs, or crawlers, of most mealybug species display dispersal actively. Other nymphal stages and adult females may also move limited distances (Kosztarab and Kozár, 1988) but, similarly to most scale insects, crawlers are the mealybugs' main dispersal agents. There is evidence that this developmental stage of scale insects is dispersed passively by the wind, and may be carried for distances of a few meters to several kilometers, or even more, from the natal plant–host, although mortality is very high (Gullan and Kosztarab, 1997). In contrast, Williams and Granara de Willink (1992) reported that mealybugs were believed to be distributed by air currents over only short distances. As well as wind, water, bed-soil, humans, and domestic and wild animals may aid the passive dispersal of mealybugs (Kosztarab and Kozár, 1988). Among arthropods, ants have also been reported to disperse some mealybug species (Gullan and Kosztarab, 1997; Malsch et al., 2001; Ranjan, 2006). Nevertheless, if conditions are favorable, crawlers usually settle on the natal host plant, often close to their mother, which leads to an aggregative distribution (Gullan and Kosztarab, 1997; Nestel et al., 1995).

Many species of mealybugs have been widely distributed by commercial traffic, mostly carried on imported plant material (Williams and Granara de Willink, 1992). Because of their cryptic habits and small size, mealybugs are difficult to detect at borders during quarantine inspections, especially if their population density on plants is low (Gullan and Martin, 2003).

2.2.9 Mealybug relationships with ants

Ants are often associated with mealybugs as honeydew consumers. Hemiptera-tending ants are mostly species of the subfamilies Myrmicinae, Dolichoderinae, and Formicinae (Degen and Gersani, 1989; Mittler and Douglas, 2003). The tended mealybugs benefit from the protection against natural enemies, and the removal of honeydew prevents contamination, which may be especially detrimental to first-instar nymphs (Cudjoe et al., 1993; Daane et al., 2006b, Daane et al., 2007; Gullan and Kosztarab, 1997; Moreno et al., 1987). Some ant species actively construct shelters for mealybugs which provide some protection from unfavorable environments and natural enemies (Franco et al., 2000; Helms and Vinson, 2002; McLeod et al., 2002) leading to frequent mealybug outbreaks (Daane et al., 2006b, Daane et al., 2007; Silverman and Brightwell, 2008).

Several studies have documented that ant attendance reduces the parasitism of honey-dew excreting Hemiptera through attacks and disturbances against parasitoid foraging activities or oviposition attempts (Martinez-Ferrer et al., 2003; Itioka and Inoue, 1996; Stechmann et al., 1996; Vinson and Scarborough, 1991; Novak, 1994). Whitehead (1957) and Myburgh (1986) reported that ant foraging on plant canopies reduces natural enemy activity and promotes mealybug infestation and therefore, biological control of the insect pest is compromised. For example, Flanders (1945) documented an increase in the yellow scale, *Aonidiella citrina* Coquillet (Hemiptera: Diaspididae), and a decrease in parasitism by endoparasitoid *Comperiella bifasciata* Howard (Hymenoptera: Encyrtidae) in the presence of Argentine ants, *Linepithema humile* (Mayr) (Compere, 1940). Flander (1943) and Compere (1940) reported that in South Africa *Metaphycus helvolus* (Compere), a parasitoid of black scale was found to be effective only in the absence of *L. humile*. In California, Daane et al. (2007) found that *L. humile* promoted populations of obscure mealybug *Pseudococcus viburni* (Signoret) while lowering populations of its parasitoids *Pseudaphycus maritimus* (Erhorn) accompanied by a serious reduction in its parasitoid populations. The common pugnacious ant, *Anoplolepis custodiens* (Smith) has also been reported to incidentally disturb the parasitoids of California red scale, *Aonidiella aurantii* (Maskell), while tending soft brown scale in citrus orchards in South Africa (Samways and Tate, 1984; Steyn, 1954). The cocktail ant *Crematogaster peringueyi* Emery is disruptive to natural enemies of soft brown scale *Coccus hesperidum* L., and vine mealybugs *Planococcus ficus* (Signoret) (Kriegler and Whitehead, 1962). The Argentine ant, *L. humile* was found to be disruptive to the black scale, *Saissetia oleae* Olivier, parasitoid *Coccophagus scutellaris* (Dalman) in California (Horton, 1918).

In Australia, Buckley and Gullan (1991) found that the incidence of coccid parasitization was correlated with the relative inoffensiveness of the attendant ant species in a field study. Buckley and Gullan (1991) reported a very low parasitism rates (< 10%) of coccids in the presence of *Oecophylla* and *Solenopsis* species and > 15% in the presence of the more aggressive *Tapinoma* and *Iridomyrmex* species. In California, *L. humile* reduced parasitism and host mutilation of the California red scale by the parasitoid *Comperiella bifasciata* (Howard) (59.1%) and *Aphytis melinus* DeBach (79.5%) in a laboratory trial (Martinez-Ferrer et al., 2003). Itioka and Inoue (1996) in a comparative field investigation found a 94% decrease of the mealybug *P. citriculus* populations in a Satsuma orange orchard by natural enemies in the absence of the attendant ant, *Lasius niger* Linnaeus (Hymenoptera: Formicidae). In the absence of Argentine ant, populations of the citrus mealybug, *Planococcus citri* Risso (Hemiptera: Pseudococcidae), and the wooly whitefly, *Aleurothrixus floccossus* Maskell (Homoptera: Aleyrodidae), were effectively reduced by their respective natural enemies (Moreno et al., 1987).

2.2.10 Management of mealybugs

2.2.10.1 Biological Control

2.2.10.1.1 Natural enemies

Mealybugs have many natural enemies, including parasitic wasps, arthropod predators and entomopathogenic fungi. However, parasitoid encyrtids (Hymenoptera, Encyrtidae) and predatory lady beetles (Coleoptera, Coccinellidae) are the most common natural enemies of mealybugs. Mealybug-parasitizing encyrtids are primary endoparasitoids; most of them undergo solitary development. Their host specificity is not a clear issue. Franco et al. (2000) compiled, from published literature, about 70 encyrtid parasitoid species that were reared from the citrus mealybug, whereas only four species were considered to be principle parasitoids of this mealybug. *Coccidoxenoides, Gyranusoidea, Leptomastidea, Leptomastix, Pseudaphycus*, and *Tetracnemoidea* are examples of encyrtid genera of mealybug parasitoids (Charles, 1993; Franco et al., 2000; Noyes and Hayat, 1994; Rosen, 1981). The most up-to-date assessment of parasitoids attacking *R. iceryoides* in its native home is provided by Noyes and Hyat (1994). The most important parasitoids of *R. iceryoides* in India are *Anagyrus chryos*, *A. sabas, An. agraensis, A. mirzai, Leptomastrix nigrocoxalis* and *Praleurocerus viridis*.

Coccinellids accept a wide range of food, but they complete larval development and produce viable progeny only if they consume their ‘essential food’. Four genera of Chilocorinae (*Brumus*, *Aspidimerus*, *Stictobura* and *Orcus*) and six of Scymninae (*Diomus*, *Nephus*, *Sidis*, *Parasidis*, *Cryptolaemus* and *Pseudoscymnus*) prey preferentially on mealybugs (Iperti, 1999). Other important groups of predators are brown lacewings (Neuroptera; Hemerobiidae) and predatory gallmidges (Diptera; Cecidomyiidae). The most important predators of *R. iceryoides* in India include: *Aponephus lentiformis* gen. et sp. nov., *Cryptolaemus montrouzieri* Mulsant, *Scymnus coccivora* Ayyar and *Spalgis epeus* Westwood. The lycaenid, *S. epius*, clears complete infestations of *R. iceryoides* when it feeds (Vasundhara et al., 1990).

As sap feeders, mealybugs are not likely to be exposed to viral or bacterial infections (Moore, 1988) and only a few species of entomopathogenic fungi were reported to be associated with mealybugs and confirmed to be pathogenic; they include *Aspergillus parasiticus* Speare, *Cladosporium oxysporum* Berk. and M.A. Curtis, *Hirsutella sphaerospora* H.C. Evans and Samson, and *Neozygites fumosa* (Speare) Remaudière and Keller (Browning, 1994; Delalibera et al., 1997; Leru, 1986; Moore, 1988; Samways and Grech, 1986).

It is apparent that given natural enemies may flourish in some situations and perform poorly in others. There are numerous cases at hand showing limited abilities of natural enemies to attack respective hosts in one region contrasted to their capabilities against the same hosts in some other regions. An excellent example of climatic limitation is that of the citrus black fly parasitoid, *Eretmocerus serius* Silvestri (Insect: Hymenoptera). When this parasitoid was introduced from Malaysia into Cuba, Trinidad, Brazil and Costa Rica, it became well established and soon provided very effective control of the pest. However, when it was introduced into western Mexico, establishment occurred but only in scattered areas, and little control was realized. The parasite clearly was not well adapted to the severe winters and arid summers prevailing in many regions in Mexico (Clausen, 1958; Messenger and Bosch, 1971). A more recent case is the introduction of natural enemies against the cassava green mite in Africa.

Populations of *Neoseiulus idaeus* (Demmark and Muma) and *Typhlodromalus manihoti* (Moraes) were imported from Columbia to Africa but none of them ever became established in the wide range of agronomic and ecological conditions tested, apparently because of inadequate alternative food sources and extended periods of low relative humidity. However, populations of the same species introduced from Northeastern Brazil were released and have since established and spread into various African countries (Yaninek et al., 1993). Natural enemies may therefore be soughted in the native home of the pest and in areas with climate similar to that of the destination (Legner and Bellows, 1999). In classical biological control attempts, particular attention should be paid in searching and introducing ecologically compatible natural enemies to increase their probability of establishment.

2.2.10.1.2 Classical biological control

Biological control of mealybugs has been practiced for many years; it involves three main tactics, that is, classical biological control, augmentative releases, and conservation biological control. However, since the major mealybug pests are invasive species, classical biological control has been the major control tactic. Moore (1988) reviewed the natural enemies used against mealybugs in biological control programs worldwide. According to him, more than 70 species of parasitoids have been introduced against mealybugs, and at least 16% of the introductions were considered to cause substantial or complete control. Most of the introduced parasitoid species were encyrtids, but species of Aphelinidae and Platygasteridae proved to be successful on several occasions. Often a single parasitoid was considered to be responsible for the success, even when more than one was introduced. Noyes and Hayat (1994) reviewed the use of encyrtids for biological control of pest mealybugs, and found that out of a total of 385 importations of encyrtids, targeting 22 mealybug species, about 24 and 7% were considered to give partial or successful control in the field and in greenhouses, respectively.

With regard to predators, Moore (1988) analyzed the use of *C. montrouzieri* separately from that of other mealybug predators. This lady beetle has been used many times against at least 10 different species of mealybugs and was considered to give substantial or partial control in about 19% of the introductions; on some occasions it has been regarded as an outstanding biological control success. Of the other 46 predator species – mostly coccinellids, but also cecidomyiids, chrysopids, hemerobiids and lycanids – used in biological control of mealybugs, only the cecidomyiid *Kalodiplosis pseudococci* Felt was regarded as having given significant control, when used against *Dysmicoccus brevipes* (Cockerell) in Hawaii in conjunction with two parasitoids.

Stiling (1993) in his analysis of why in biological control campaigns, some introduced enemies fail to reduce pest populations substantially, showed that the major reason given for failure is related to climate (34.5%). Moore (1988) analyzed the reasons for the failures of both parasitoids and predators of mealybugs to become established in biological control programs. In the case of parasitoids he cites the following documented reasons: (i) incorrect identification of the target mealybug species; (ii) the target was a native species; (iii) hyperparasitism; (iv) failure of the parasitoid to adapt to unfavorable climates; and (v) other reasons, such as interference with ants, use of pesticides, and small numbers of individuals released. With regard to predators, Moore (1988) listed six main reasons for failure: (i) no adaptation of the released species to climate; (ii) effect of pesticides; (iii) density of the prey; (iv) effect of the host plant; (v) inability to reach the prey; and (vi) effects of other organisms.

The lack of adequate food resources for natural enemies within or near to agroecosystems may limit the performance of biological control agents against mealybugs. For example, Davies et al. (2004) observed that the survival and reproduction of *Coccidoxenoides perminutus* Girault, a parasitoid of the citrus mealybug, *P. citri*, was significantly influenced by the nature of the nectar on which the parasitoid was fed. In light of these results, it was suggested that habitat management, for example, by providing suitable nectar sources for adult parasitoids, might be a means to conserve and enhance *C. perminutus* activity in the field.

In recent years successful classical biological control programs against mealybugs have targeted the cassava mealybug, *Phenacoccus manihoti*, in Africa (Neuenschwander, 2001), the mango mealybug, *R. invadens* in West Africa (Bokonon-Ganta et al., 2002), the pink hibiscus mealybug, *Maconellicoccus hirsutus* (Green) in the Caribbean and California (Roltsch et al., 2006), and the papaya mealybug, *Paracoccus marginatus* Williams and Granara de Willink, in Palau (Muniappan et al., 2006). It is important to note that successes were mostly achieved in tropical regions where the target area for classical biological control and the area of origin of the introduced parasitoids displayed similar climatic conditions.

In a few cases modeling has been used as a tool to analyze actual systems and to identify major constraints, in order to improve biological control of mealybugs. For example, the model developed by Gutierrez et al. (2008a) predicted that the parasitoid *A. pseudococci* would have a larger impact on the vine mealybug, *P. ficus* than either *L. abnormis* or *C. montrouzieri*, and that biological control of the mealybug in California would require additional species of natural enemies and/or could be achieved by reducing the size of the spatial-temporal refuge. In another use of a modeling approach, Gutierrez et al. (2008b) concluded that biological control of the vine mealybug might be adversely affected by climate change. Gutierrez et al. (1993) developed a tritrophic model of the cassava system, and used it to explore the basis for the successful control of cassava mealybug, *P. manihoti* in Africa by the exotic parasitoid *Epidinocarsis lopezi*

(DeSantis), and also to examine the causes for the failure of the related parasitoid *E. diversicornis* (Howard) to establish itself.

2.2.10.1.3 Augmentative control tactics

When the mealybug population is low, the population densities of its specific natural enemies, especially the predators, are also low. Parasitoids, which are better fitted to survive at low mealybug densities, may find it difficult to reach their hosts in their most appropriate refugia, and these small colonies may also be well protected by ants. However, inoculative or inundating releases of parasitoids may compensate for their low survival. Augmentation of the parasitoid population, when mealybugs leave their typical refugia for new colonization sites on the host plant, may improve the mealybug/parasitoid ratio (Mendel et al., 1999). If the population density during a particular season is low, released parasitoids tend to disperse over a rather large area in their search for mealybug colonies (Mendel et al., 1999). The kairomonal response of the parasitoids to the mealybug sex pheromone can be utilized to keep the released individuals in the targeted area. The parasitoids search for mealybugs in the vicinity of the pheromone release points (Franco et al., 2008c), therefore, the intensity of parasitization may be increased in treated plots. Another tactic that may be considered involves measurement of the population of natural enemies in the managed area. Advance acquisition of information should be considered, in order to plan augmentation of natural enemies in the coming growing season. It is expected that if there was considerable mealybug mortality in a particular area, it might be attributed to the activity of parasitoids and predators that had survived in these areas, and not because of migration of natural enemies from a long distance. Therefore, information about the natural enemy density late in the season may be achieved by setting up traps baited with mealybug colonies, with or without the sex pheromone (with respect to each individual case).

The first known case of an augmentative biological control program dates back to before 1917 and was aimed at controlling the citrophilus mealybug, *P. calceolariae*, a pest of citrus in Southern California, by using the coccinellid predator *C. montrouzieri* (Luck and Forster, 2003; van Lenteren, 2006). Since then, this Australian ladybird beetle has been commonly used in various countries on diverse crops (Copland et al., 1985; Franco et al., 2004b), and is actually one of the few species of natural enemies commercially available for biological control of mealybugs by means of augmentative tactics. Augmentative releases of *L. dactylopii* and *C. montrouzieri* against *P. citri* have been reported to be effective in several Mediterranean countries, and in other citrus-growing areas, such as Australia and California. However, Mendel et al. (1999) released 5,000–10,000 individuals of *L. dactylopii* or 10,000–50,000 of *A. pseudococci* per hectare and obtained no significant impact on either the mealybug infestation or on fruit damage.

2.2.10.1.4 Pheromone-based management tactics

Sex pheromones of insects, including mealybugs, are natural compounds emitted by virgin females in order to attract conspecific males for mating. The sex pheromones are effective in extremely small quantities; they are non-toxic and can be applied in various ways. Unlike pesticides, these chemicals are species-specific and do not affect beneficial insects. The behavioral impacts of the semiochemicals are limited to the target pest organisms. The potential of mealybug sex pheromones as an alternative and ecologically friendly means for monitoring and control is important and promising. Sex pheromones are used in lures for monitoring, detection of outbreaks, and for population management. Monitoring systems provide vital information for the timing of insecticide applications. Population levels can be reduced or controlled by mass trapping, mating disruption, or lure and kill. The success of these methods depends on the availability of the pheromone, and on an appropriate formulation and deployment.

Because of the worldwide economic importance of the pest, there is a need to improve the efficiency of pheromone synthesis and to make the pheromone available for control application. A series of analogs of this pheromone was prepared, in order to find a less expensive attractant (Liu et al., 1995; Dunkelblum et al., 1987), but most of them were insufficiently attractive, except for a homolog in which a cyclobutaneethanol moiety replaced the cyclobutanemethanol moiety in the natural pheromone. The advantage of the homolog is that its synthesis is easier and less expensive than that of the pheromone.

2.2.10.1.5 Kairomonal response

The sex pheromone of mealybugs may be used by their natural enemies as a kairomonal cue in host or prey selection. Millar et al. (2002) suggested that *A. pseudococci* (most likely *Anagyrus* spec. nov. near *pseudococci*) in California vineyards was attracted to the pheromone of *P. ficus*. Franco et al. (2008c) showed, in light of both field and olfactometer experiments, that the females of the encyrtid *Anagyrus* spec. nov. near *pseudococci*, a major parasitoid of both the vine mealybug, *P. ficus* and the citrus mealybug, *P. citri* were attracted to the sex pheromone of *P. ficus* but not to that of *P. citri*, and that this kairomonal response was an innate behavior trait. This host–parasitoid relationship has been further investigated, and preliminary data from field trials in which sentinel mealybugs on sprouted potatoes were exposed in citrus orchards, suggested that the presence of *P. ficus* sex pheromone significantly increases the parasitization rate of *P. citri* colonies by *Anagyrus* spec. nov. near *pseudococci* (Franco et al., 2008b). Similar kairomonal responses have been suggested in a few other parasitoid species of mealybugs. Rotundo and Tremblay (1975) reported that traps baited with virgin females of *P. calceolariae* captured significant numbers of the encyrtid *Tetracnemoidea peregrina* (Compere) (=*Arhopoideus peregrinus*). A kairomonal response of the encyrtid *Pseudaphycus maculipennis* Mercet to the sex pheromone of the obscure mealybug, *P. viburni* was also observed in field experiments with pheromone traps (Bell et al., 2008; Bell et al., 2006). Two species of mealybug parasitoids were caught in traps baited with the sex pheromone of *P. cryptus* in a citrus orchard in Japan (Arai, 2002).

The kairomonal response of a parasitoid to the sex pheromone of its host mealybug could impair its practical use for mealybug pest management by mass trapping and lure-and-kill tactics (Franco et al., 2008c). This side effect may be avoided by using pheromone analogs that lack kairomonal activity but that still preserve the pheromonal attractiveness to the males, as was successfully accomplished for other scale insects, for example, *Matsucoccus* spp. (Mendel et al., 2003). Optimizing the devices used in these tactics, for example, with regard to design and color, could also minimize the negative impact on natural enemies of the pests (Franco et al., 2008c).

The results obtained by Walton et al. (2006) with pheromone-based mating disruption of vine mealybug indicated that the treatment had no negative effect on the level of parasitization of *P. ficus* by *A. pseudococci*. Franco et al. (2008c) suggested that the kairomonal response of

Anagyrus spec. nov. near *pseudococci* could be explored in connection with biological control tactics, by enhancing para- sitization of *P. citri* as a component of integrated pest management strategies, by means of a similar approach to that used against aphid pests (Powell and Pickett, 2003). The use of semiochemicals for enhancing the effectiveness of biological control tactics against pest mealybugs offers a potential novel approach that needs further investigation and exploration.

2.2.10.2 Chemical control

There are great similarities among the insecticide arsenals used to control mealybug species on different crops. An insecticide arsenal that is both suitable for organic farming and able to cope effectively with mealybug pests does not exist in practice. Since the growers will need to treat small hot spots of the mealybug, it is expected that some soft insecticides will be used and that more than one application may be needed, to selectively eliminate such hot spots. When these hot spots are treated several points should be taken into account: (i) hot spots are expected to be in areas that are practically free of problematic mealybug populations; they actually constitute oases for parasitoids and predators; therefore, the ratio of mealybug to natural enemy populations in the hot spots should be considered before initiation of any control operation; (ii) an insecticide will be applied when augmentation with predators is not useful or cannot be implemented; (iii) a low-residue short-life insecticide is the most appropriate; (iv) augmentation of natural enemies will be needed if the hot spots are too numerous.

In principle, three main modes of insecticide application are adopted: (i) foliage cover spraying for management of above-ground populations; (ii) application of insecticide solution to the soil to enable it to penetrate to the root zone, so as to combat subterranean colonies; and (iii) chemigation by application of systemic compounds via the irrigation system, for example, drip irrigation. Systemic insecticides are also used against mealybugs by smearing them on the stem or main branches. Two other, less common, techniques are fumigation, usually applied for eradication, for example, with methyl bromide, or slow-release strips to prevent colonization. Organophosphates – such as chlorpyrifos, acephate, dichlorvos and diazinon – and, to a lesser extent, carbamates – such as aminocarb, carbaryl, thiodicarb or methomyl – are broad-spectrum nerve insecticides which have been used against mealybugs that colonize the plant canopy since the early 1960s (e.g., de Souza et al., 2007; Gonzalez et al., 2001; Shafqat et al., 2007). These insecticides when applied in high volume could successfully overcome the obstacles that make mealybugs hard to kill: (i) their hydrophobic wax cover, which repels hydrophilic insecticides; (ii) their tendency to feed in hidden and protected parts of the plant; (iii) their typically dense colonies; and (iv) the frequent overlapping of generations. Effective control is achieved when most of the mealybug population is in the dispersive crawler stage or the young nymphal instars, and when the host plant does not provide effective shelter. However, satisfactory control is often difficult to achieve over an extended period. These chemicals have detrimental effects on the environment as a whole and on natural enemies in particular (Anand and Ayub, 2000; Babu and Ramanamurthy, 1998; Meyerdirk et al., 1982). The multivoltinous character of pest mealybugs and the frequent application of inefficient control measures accelerate the development of insecticide resistance (Flaherty et al., 1982). Systemic organophosphates such as dimethoate could overcome some of these obstacles (Grout and Stephen, 2005; Meyerdirk et al., 1982; Prasad et al., 1998). Pyrethrins and rotenone replaced these compounds in organic agriculture with limited effectiveness. Chlorpyrifos-impregnated strips are applied to protect banana bunches from mealybug infestation or as stem barriers for the control of ants (Addison, 2002; Gross et al., 2001).

Oils have long been used for the control of scale insects but they have been ineffective against mealybugs. However, integration of narrow refined oils with other insecticides was suggested as a means to dissolve the insect’s wax covering and thereby improve the insecticide efficacy (Cranshaw et al., 2000; Morishita, 2005). Insect growth regulators (IGRs), such as buprofezin, a chitin-synthesis inhibitor, or kinoprene, which mimics juvenile hormone, were sought as replacements for organophosphates and carbamates in controlling mealybugs; they have been considered a suitable alternative because they exhibit low human toxicity, they are more selective to many beneficial species, and they are specifically targeted at processes involved in particular stages of mealybug development. However, many of the IGRs are toxic to ladybeetles (James, 2004; Cloyd and Dickinson, 2006). Buprofezin is a commonly applied IGR against mealybugs (Muthukrishnan et al., 2005); however, its effectiveness is mainly limited to eggs and young stages, so that adult females may escape the consequences of the treatment. Buprofezin also suffers from the same limitations as other foliarly sprayed compounds. More recently, an effective group of compounds has been found which combine toxicity to mealybugs with safety to other non-targeted organisms; they are the neonicotinoids. These compounds act on the central nervous system, and easily replace carbamates, organophosphates or pyrethroids, since there are no records of cross-resistance associated with them. These systemic compounds show high effectiveness against mealybugs. Examples include: dinotefuran applied to the canopy; acetamiprid applied by smearing on the stem or the branches (Gross et al., 2000; Larrain, 1999); and imidacloprid and thiamethoxam that are introduced by watering the soil (Daane et al., 2006a; Daane et al., 2006b; Fu Castillo et al., 2004; Grout and Stephen, 2005; Martin and Workman, 1999; Sazo et al., 2006). In organic agriculture, azadirachtin, an IGR chitin inhibitor derived from the Indian neem tree, may be used in similar modes (Irulandi et al., 2001).

2.2.10.3 Cultural control

Cultural control has long been observed to slow the spread of mealybug infestations in orchards. The following tactics can be applied in mealybug infested mango orchards:

1. Work in mealybug infested orchards should be scheduled such that once pruners or harvesters are done with work in the orchards; they are finished for the day. Alternatively, workers should be asked to shower and change their clothes before entering an uninfested orchard. Showering and change of clothings are necessary because all life stages of mealybug (particularly, crawlers) can be carried on the workers' skin, clothing and hair. These mealybug life stages can survive for eight to 24 hours and therefore can lead to new infestaions in uninfested orchards, if the cleaning protocol is not followed.
2. The prunings from an infested orchards can be treated in one of the following ways:
    - Prunings of infested plant parts should be taken out of the orchards and burnt immediately.
    - The prunings should be shredded and mulched in the middle of the row away from the mango stem. Although, shredding makes very small pieces out of the prunings, mealybug crawlers can still survive on pieces of sticks about one to two inches in length. Therefore, shreddings should be bagged in heavy-duty construction disposal bags, and the sealed bag taken away from the zone of the mango stem shortly after pruning. The

bagged prunings can then be allowed to rot or decompose for two to three weeks in the orchards.

3. The equipment used for pruning or harvesting in an infested orchard should be steam cleaned. Care should be taken to make sure all plant materials are removed.
4. For harvest targeted for the market, once the fruits are bagged and boxed, the truck bed on which the boxes are loaded should be cleaned of any plant debris before leaving the orchard. The truck should go directly to the storage facility to unload. The truck should also be steam cleaned at the storage facility before returning to any part of the orchard.
5. For fruits transported in a truck, the truck should be covered with a plastic tarp to avoid infested plant material or crawlers from being blown out of the vehicle during transport. All vehicles and tarps should then be steam cleaned as well before picking up more fruits from the orchards.
6. Removal of alternative host is also strongly advised.

2.2.10.4 Pathogens

Only the entomopathogenic fungi are recorded among the Pseudococcidae and these records are sparse and confused. The fungi that have been confirmed as pathogenic against mealybugs include: *Neozygites fumosa* (Speare), *Hirsutella cryptosclerotium* (Fern.-García, H. C. Evans & Samson), *Cephalosporium sp*. (probably *Verticillium lecanii* Zimmerman), *Aspergillus parasiticus* and possibly *Cladosporium oxysporum* (Berk & Curtis). However, practical development of these requires much research.

2.2.10.5 Integrated pest management

Worldwide, the most recommended control strategy for reducing yield loss by mealybugs that enables growers to comply with stringent quality production in export market is integrated pest management (IPM). With integrated control, chemical, biological and cultural control methods are used in conjunction with each other. Each method contributes to the total control strategy. In an integrated programme various aspects are considered to ensure an environmentally friendly, yet effective end result.

Prevention is better than cure. This principle is highly applicable in the management of mealybugs, which are hard to kill pests on several crop plants. This is because mealybugs form colonies in protected areas of the plants and all the life stages are covered with waxy coating, therefore, making it difficult to control with conventional insecticides. Cultural, mechanical, biological and chemical methods of control have to be adapted throughout to contain the mealybug population thus preventing the loss caused by the mealybugs. Integrated pest management of mealybugs will therefore include the following steps:

- The infested plant portions with mealybug colonies should be prunned during the dry season to expose eggs or nymphs to natural enemies and sun heat and/or destroyed. Fallen infested leaves under the tree canopy should be collected and burnt to avoid further spread of the pest.
- Infested fruits on the trees at the time of harvesting should be collected and destroyed.
- All the pruned materials from mealybug infested orchards should be collected and destroyed.
- To combat the menance caused by mealybugs in orchards, regular monitoring and early detection of infestation are essential. Mango orchards and neighbouring areas should be free from other suitability host plant capable of harbouring mealybug populations in and around the orchards throughout the year.
- Ant colonies associated with mealybugs in orchards should be located and destroyed with drenching of chlorpyriphos 20 EC @ 2.5 mL/L or apply malathion 5% dust @ 10 kg/ac, since ants are known to be associated with the build-up of mealybug populations.
- In orchards where mealybug incidence is widespread, periodic prunning of affected portions coupled with spray of dichlorvas 76 WSC 0.2% (@ 2.5ml/lit) or methyl parathion 50 EC 0.05% (@1ml/lit) or dimethoate 30 EC 0.05% (1.75ml/lit) in combination with fish oil resin soap @ 20g per litre of water should be used to reduce mealybug incidence.
- The same insecticides should not be repeated in subsequent rounds as rotation of insecticides would be desirable to counteract the tendency of the mealybugs to develop field resistance.

- Insecticidal spraying in infested orchards should be carried out in such a way as to cover the entire lower surface of leaves, twigs and branches where all the meaybug life stages are known to occur in large numbers. It is important for insecticide spraying to be carried out in the evening hours to avoid toxicity to non target insects like pollinators.
- The use of broad spectrum insecticide should be avoided to encourage the conservation of natural enemies like parasitoids and coccinelids, which are known to be efficient parasites and predators, respectively, on eggs and nymphal stages of mealybugs. For example, the release of the Australian ladybird beetle (*Cryptolaemus montrouzieri* Mulsant) @ 5000/ha or 10 beetles/plant has been shown to clear the mealybug population present in infested orchards.
- The use of neem seed extract (4%) or garlic oil (1%) on tree trunk below the alkathene band has been shown to kill congregated crawlers.