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Chapter 2

Integrated Pest Management of Coconut in Sri Lanka

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1. Introduction

Agriculture contributes about 10.1 per cent of the Gross Domestic Production (GDP) of Sri Lanka and tea, rubber and coconut sectors account for 0.9, 0.2 and 0.8 per cent of the GDP respectively at current prices (Anon, 2014a). Coconut is grown in 394, 840 ha (Anon, 2014b) with an annual national production of 3027 million coconuts (Ranasinghe *et al.*, 2016). The area under coconut is second only to the staple food, paddy, which is cultivated in more than 700,000 ha in Sri Lanka (Anon, 2014a). Coconut is predominantly grown in North-Western and Western provinces (coconut triangle) and Southern province (mini coconut triangle) of Sri Lanka. According to the world ranking in coconut production, Sri Lanka holds the fifth position (Anon, 2016a).

Coconut is a major livelihood crop of nearly 4 million people in Sri Lanka, where 70 per cent of the total produced is used for domestic consumption(Anon, 2014b), mainly as oil and milk, while the rest is exported as fresh coconut, desiccated coconut, coconut cream, milk powder, traditional oil and virgin coconut oil, coconut water, charcoal, fibre and fibre products. Coconut accounts for US$ 205 million of export earnings and 379 million coconuts have been exported as copra, oil and desiccated coconut in 2013 (Anon, 2014b).

The Sri Lankan coconut industry faces a number of challenges, both biotic and abiotic, and pests are among the major limiting factors of coconut production. During its long lifespan, different parts of the coconut palm are damaged by an array of pests. They are invertebrates such as insects and mites and vertebrates, mainly mammalian pests. However, not all pests cause damages of economic significance. The damage done by some pests cause severe economic losses as their populations are usually high in plantations, they are present all over the country and usually damage the crop throughout the year. They are not successfully controlled by natural enemies present in the environment and therefore, in most of the cases, intervention by the growers is necessary to control them. These pests are regarded as major pests of coconut. On the other hand, minor pests usually do not damage the coconut palm to an extent that will cause an economic crop loss to the grower. Their populations are usually below the economic threshold level and very well controlled by their natural enemies. Therefore, intervention of the grower is not necessary to control the minor pests. If the balance between the pest and the natural enemy populations is disturbed, pest population may rise above the economic threshold level at which point the growers' intervention is needed. Except for few, minor pests are usually restricted to certain areas and infestations are reported during certain times only. Therefore, the research on pests of coconut in Sri Lanka mainly targets on developing the management strategies of major pests only. Red palm weevil (*Rhynchophorus ferrugineus* Olivier), rhinoceros beetle (*Oryctes rhinoceros* L.), coconut black-headed caterpillar (*Opisina arenosella* Walker), plesispa beetle (*Plesispa reichei* Chapuis) and coconut mite (*Aceria guerreronis* Keifer) are the most destructive, major pests of coconut in Sri Lanka. Management of these pests has always been a formidable challenge to the coconut growers.

2. Red Palm Weevil, *Rhynchophorus ferrugineus* Olivier

Red palm weevil (RPW), a widely distributed pest in all coconut growing areas in Sri Lanka, is a serious pest that can cause fatal damage to coconut. Damage is done by the larva (grubs) of this pest. Coconut palms of 3-15 years are usually more prone to damage by RPW (Menon and Pandalai, 1960; CABI, 2015a). Adult RPW, which is characterized by dark red colour body with black spots on the thorax and a snout in the head, is about 2-3 cm long and 1 cm wide. Adult females of RPW are attracted to the fermenting odour that emanates from the fresh wounds on the trunk, pith, roots or rarely on unopened inflorescences of coconut and preferentially lay eggs on them (Menon and Pandalai, 1960; CABI, 2015a). Larvae of RPW burrow into the stem feeding on the soft tissue inside the trunk of the coconut palm. Pupation takes place inside a fibrous cocoon and adult RPW emerges from it. Several generations of RPW can damage the coconut palm simultaneously. Yellowing and drooping of leaves, slanted bud, small holes of about 0.5-1.5 cm, reddish/dark brown viscous fluid oozing out of those holes ('stem bleeding') and the crunching noise of the RPW larvae feeding on soft tissues inside the trunk are the symptoms of the infestation.

Because of the concealed nature of the damaging instar of this pest, management of RPW is enormously difficult. Current methods to control the pest have been focused on integrated pest management (IPM) with a wide range of preventive and curative measures in Sri Lanka. The IPM package for RPW in Sri Lanka includes surveillance, cultural methods, chemical methods and pheromone trapping (Anon, 2012a). However, the palm loss due to RPW damage is inordinate mainly because the coconut growers find it difficult to identify the damage at an early stage which is of paramount importance in managing the pest. Detection of the infested palms in the early stage by the conventional methods (checking for external symptoms, crunching sounds *etc.*) is time consuming, labour intensive and costly (Siriwardena *et al.*, 2010). Coconut Research Institute of Sri Lanka (CRISL), in collaboration with the University of Moratuwa, Sri Lanka has developed a portable acoustic device (Figure 2.1) for early detection of RPW damage in coconut palms (Siriwardena *et al.*, 2010). The device consists of a sensor which is made of piezoelectric transducer squashed in together with two circular stainless steel discs to acquire the sound signals from an infested palm, a signal processing unit that captures and amplifies the sound received by the sensor while filtering out the other noise signals in the environment and an output device that helps the user to determine whether the palm is infested or not (Siriwardena *et al.*, 2010). As an additional feature, a pre-recorded play-back sound clip of the RPW larval feeding sound is included in the device for the user to familiarize with the correct sound. This device is a compact, light-weight, pocket-held and robust device which is becoming popular among the coconut growers in Sri Lanka.

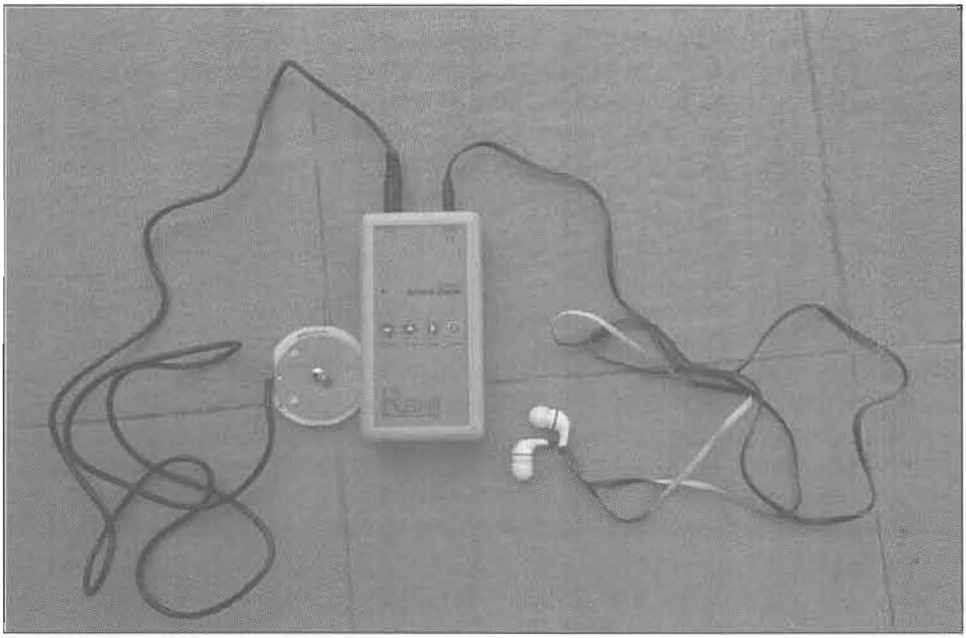

Figure 2.1: Portable Acoustic Device ReDrin™ for Early Detection of Red Palm Weevil Damage in Coconut Palms.

Cultural methods (maintenance of clean plantations by burning dead palms due to RPW, cleaning of stems of young coconut palms by removing unnecessary/ wounded fronds and other debris for early identification of the damage and maintenance of young coconut palms with minimum wounds and if fresh wounds are detected, application of coal tar or burnt engine oil) are recommended to prevent the RPW damage in coconut palms (Anon, 2012a). Once the larvae are detected inside the palm trunk, the only possible way of controlling the pest is by the application of systemic insecticides. Trunk injection and root feeding of Monocrotophos have been recommended to control RPW larvae inside the palms (Anon, 2012a).

Monocrotophos is a highly toxic insecticide and is classified in the WHO Class 1b (Anon, 2009). Due to its high toxicity, use of monocrotophos is not permitted in Sri Lanka except for few pests in coconut including RPW for which more than 95 per cent of the imported monocrotophos in to the country is used. To replace monocrotophos, alternative insecticides are being tested by the CRISL and recently two insecticides, namely phenthoate (Anon, 2012a) and a mixture of thiamethoxam 20 per cent and chlorantraniliprole 20 per cent have been recommended to control RPW in coconut. Though not as effective as monocrotophos, both insecticides, if properly administered, can kill RPW larvae inside the palm trunk.

Males and females of RPW are attracted to an aggregation pheromone, ferrugeneol (4-methyl-5-nonanol) (Gunnawardena and Badarage, 1995a; Rajapakse *et al.*, 1998) and its activity can be enhanced by N-pentanol (Gunnawardena and Badarage, 1995b). The pheromone that is artificially synthesized in the laboratory is used in a trap that has been designed using the pheromone and a 5 L plastic bucket with a raised lid and a food bait of either sugar cane or toddy or yeast (2g) + sugar (150g) + water (1L) mixture (Anon, 2012a). Insecticide solution or a soap solution is added to the bucket to kill trapped weevils. The pheromone trap is installed in the plantation, preferably at the periphery of the plantation or slightly away from the young plantation or in adult plantation to catch the weevils. The recommended trap density in Sri Lanka is 5-6 traps per ha of coconut plantation.

Long term control of economically important pests is more achievable by area-wide pest management programs using coordinated pest control tactics in large areas such as production regions than aiming at controlling the target pest temporarily in a small scale basis (*e.g.* field by field) (Elliot *et al.*, 2008; Faust, 2008; Hoddle *et al.*, 2013). Piloted by the Coconut Cultivation Board, the main extension body of the coconut industry in Sri Lanka, area-wide (>250 ha) national extension campaigns and trapping programs, advocating the integrated management of RPW has resulted in 40-50 per cent reduction in damage incidence, reflected by the drop in rate of pesticide application (M Silva, Coconut Cultivation Board, pers. comm).

3. Rhinoceros Beetle, *Oryctes rhinoceros*

Rhinoceros beetle is widely distributed in many coconut growing countries in the world (CABI, 2015b). It can cause economic damage to the seedlings and young palms, resulting in retardation of growth and sometimes even death of the young seedlings. On adult palms, an average of 10 per cent of fronds damaged by rhinoceros beetle damage-simulated cuts has resulted in 3 per cent reduction of the leaf area and a 4-5 per cent loss of nut production (Zelazny, 1979). Damage is caused by the adult through feeding on the growing frond of the coconut palm.The pest has a wide host range including *Agave sisalana* (sisal hemp), *Ananas comosus* (pineapple), many palm species, *Carica papaya* (papaya), *Colocasia esculenta* (taro), *Musa paradisiaca* (plantain), Pandanus (screw-pine) and *Saccharum officinarum* (sugarcane) (CABI, 2015b).

Adult rhinoceros beetle is easily identified by its black colour and the horn on its head ('cephalic horn') which is longer in males than in females (CABI, 2015b).

Adult female lays about 90-100 cream/white eggs during its life period of 2-4 months in decaying organic matter such as cow dung pits, coir pits and organic manure (Goonewardene, 1958; Hurpin and Fresneau, 1967). Larvae feed on the organic matter where the pupation also takes place (CABI, 2015b). Adult rhinoceros beetles make short, straight, horizontal burrows towards the centre of the coconut frond and then vertical tunnels towards the bud region (Bedford, 1976; Gressitt, 1953; Catley, 1969). Fibrous materials that have come out from the burrow or sometimes the adult rhinoceros beetle could be seen at the opening of this burrow. The damage of adult rhinoceros beetle is seen as geometric 'V' shaped cuts and holes on the frond once it is opened (Wood 1968; Sadakathulla and Ramachandran, 1990). When the flag leaf is damaged by the rhinoceros beetle it will be hanging from the top. Crooked bud leaf with retarded growth of the seedling occurs when the young seedling of less than a year is damaged and if the growing point of the young seedling is seriously injured, it will be fatal to the seedling.

Management of rhinoceros beetle is hard because they are robust, long-lived, fecund, cryptic (both adults and immatures) and nocturnal. Availability of breeding sites in abundance, difficulty in applying control measures in tall palms, inefficiency in transmitting entomopathogenic agents (while mating and at breeding sites only) among the populations and inability to mass produce rhinoceros beetles for laboratory assays also contribute to the difficulty in controlling the pest. In Sri Lanka, IPM is recommended for effective control of the rhinoceros beetle. Current IPM based strategies for rhinoceros beetle in Sri Lanka include removal of breeding sites, extracting beetles using metal hooks, application of coal tar or burnt engine oil on innermost leaf bases to repel the adult beetles, placing naphthalene balls at the leaf bases, insecticides and biological control.

Metarhizium anisopliae (Metsch.) Sorokin one of the biological control agents that have been recommended to control both adults and larvae of rhinoceros beetle in Sri Lanka. Known commonly as the green muscardine fungus (GMF), it has been recommended to apply into the breeding grounds or the infested beetles be released into the field (Suwandharathne and Kumara, 2007; Fernando and Aratchige, 2014). No significant difference in the mycelial growth and spore production of Sri Lankan and a Philippine isolate of GMF was observed, however, the mycelial growth of the local isolate significantly differed among the temperatures of 25, 27.5, 30 and 32.5°C with the highest growth at 27.5°C and lowest at 32.5°C (Subhathma *et al.*, 2012). Sri Lankan isolate produced more spores compared to the Philippine isolate and it was higher at 25°C and 27.5°C in the Sri Lankan isolate and at 25°C in the Philippine isolate (Subhathma *et al.*, 2012). These authors also confirmed that the cumulative mortality of the third instar larvae was higher with the local isolate (67 per cent) than with the Philippine isolate (42 per cent) and LT_{50} values were 14 and 18 days respectively for the two isolates. It is evident that local isolate of GMF is not suitable under all environmental conditions in Sri Lanka and it is more suitable for wet- and intermediate-zones than the dry-zone where the ambient temperature sometimes exceeds 30°C (Subhathma *et al.*, 2012). GMF is easily mass produced on-farm using maize grit (Suwandharathne and Kumara, 2007) and is applied to breeding grounds or artificial impregnation boxes of 1m x 1m x 0.5m which is filled with breeding medium (a mixture of coir/saw dust and cow dung) to transmit the disease to other individuals (Singh and Arancon Jr., 2007).

Another biological control agent, the *Oryctes* virus (OrV), is also recommended to control rhinoceros beetle in Sri Lanka. Adult rhinoceros beetles are force-fed or allowed to wade through a suspension OrV and released into the field to infect the field population of rhinoceros beetle. Both GMF and OrV are not readily transmitted by themselves and this is considered a drawback of using them. Another point to be added is the low survival of GMF particularly in dry areas. Performance of GMF on rhinoceros beetles depends on the interaction between temperature and humidity (Anon, 2015). The LTe_{50} of the fungal conidia negatively correlates with the relative humidity and the humid environments coupled with high temperatures are detrimental to the spore viability (Anon, 2015). However, high humidity with average temperatures and over casted weather with intermittent rains are favourable for disease development (Nirula, 1957). Apart from that, the limited mobility of GMF between the breeding grounds also hurdles its use. Maintenance of mother cultures of OrV has been difficult as it needs refrigeration facilities and therefore the involvement of either government or private sector institutions to assist the growers is crucial in practicing biological control of the rhinoceros beetle.

Mass trapping using the aggregation pheromone, ethyl-4-methyl octanoate which attracts both male and female beetles, is an effective way to reduce the rhinoceros beetle population (CABI, 2015b; Bedford 2013; Norman and Basri; 2004; Oehlschlager, 2007; Bedford, 2014). Use of this pheromone at the trap density of 1 per ha is recommended with two types of traps (Anon, 2012b). One type of trap, 'PVC tube trap' is made of 1.5 m long and 10-15 cm diameter PVC pipe. Two windows, 10x10 cm^2 each are made on either side at a distance of 0.5m and 0.75 m from one end. Close to the other end, few holes are made to drain excess rain water. This end is closed with an end-cap or any other closely fitting lid and fix on the ground vertically by the aid of a pole or may be attached to a trunk of an adult palm. Pheromone sachet is fixed on one window using a wire (Singh and Arancon, 2006). The beetles attracted to the pheromone fall into the pipe and are killed manually or using an insecticide/soap solution. The other type of trap (cross vane trap) is made of a plastic bucket of 10 liters and two metal sheets of the diameter of the bucket and a height of 0.5 m, arranged at an angle of 90° by making a slit on each sheet halfway (Anon, 2016b). Cross vanes are pushed into the opening of the bucket and made to stand erect by removing a triangular portion of the metal. Few holes on the lower side of the bucket are made to drain excess water. A soap-water solution is filled up to the level of the holes. The pheromone sachet/vial is hung on the middle of the vanes. The beetles attracting to the pheromone, hit the metal vanes and drop into the soap-water solution and die.

Use of pheromone traps has proven to be effective in trapping rhinoceros beetles and thereby decreasing the damage levels with different success rates in adult plantations (Suwandharathne, unpublished data). However, practically the growers are encouraged to use the traps in large plantations or if growers of small plantations desire to use these traps, to install them in few adjoining plantations simultaneously and practice area-wide trapping. It is also advised to install the traps preferably along the periphery of the plantation or in non-coconut areas. However, placing pheromone traps at the border of the plantation has found to effective only in blocks without infested breeding sites (Desmier *et al.*, 2001; Loring, 2007).

4. Coconut Black-headed Caterpillar, *Opisina arenosella*

Coconut black-headed caterpillar, a foliage pest is an outbreak pest in many coconut growing countries (Perera *et al.*, 1988). Adult coconut caterpillar is a brown moth of about 1.2 cm. Adult females lay cream colour eggs on lower surface of the coconut leaflet (Perera, 1987; Perera *et al.*, 1988) and they hatch into larvae, which is the damaging instar. In Sri Lanka, the pest is not widely prevalent in all coconut growing areas but restricted to certain areas mainly in the dry and intermediate-zones. However, recent information has shown pest outbreaks in new areas.

Coconut plantations damaged by the black-headed caterpillar can be recognized from the distance by the burnt appearance of the palms. When the damaged fronds are closely observed, green (at the initiation of the damage) or brown patches on the upper surface of the leaflets and brown galleries on the lower surface of the leaflets are seen. In an outbreak, sometimes the larvae can damage the outer skin of the fruit too. Cultural (cutting and burning of damaged fronds or portion of fronds if 5 fronds in less than 30 palms are damaged), biological and chemical control are recommended to control the coconut black-headed caterpillar in Sri Lanka (Anon, 2012c). As biological control agents, larval (*Eriborus trochanteratus* Morley, *Bracon hebetor* Say and *Goniozus nephantidis* Muesebeck) and pupal (*Brachymeria nephantidis* Gahan) parasitoids are used to control the pest. Spraying of Carbosulfan 20SC is recommended for seedlings (Anon, 2012c).

5. Coconut Mite, *Aceria guerreronis*

Coconut mite was first described from the specimens collected in Guerrero, Brazil by Keifer (1965) and later it has been reported in many coconut growing countries in America and Africa (Navia *et al.*, 2013). In late 1990's the pest expanded its range eastward towards Asia, where the first occurrence was reported from Sri Lanka and India, almost simultaneously (Fernando *et al.*, 2002; Sathiamma *et al.*, 1998). In Sri Lanka, the coconut mite infestation was first reported from the Kalpitiya Peninsula (North Western Province, dry-zone) (Fernando *et al.*, 2002). Within two years, it has spread to almost all coconut growing areas in the dry- and intermediate-zones of the country and few coconut growing areas in the wet-zone (Fernando *et al.*, 2002; Fernando and Aratchige, 2010; Aratchige, 2014). At present, the coconut mite has invaded all districts except Nuwara Eliya which is mainly a hilly area where coconut is not as extensively grown as in other districts. The incidence of coconut mite varies from district to district with higher incidences in dry- and intermediate-zones than in the wet-zone (Fernando and Aratchige, 2010; Aratchige, 2014).

Coconut mite is microscopic (205-255 µm in length and 36-52 µm in width), worm-like and white (Keifer, 1965) and feeds on the meristematic zone of the coconut fruit causing physical damage. Symptoms of the damage are first seen as a triangular white patch on the fruit surface next to the margin of the perianth and later as the infested fruit grows, the surface becomes necrotic and suberized with deep, longitudinal fissures and gummy exudates. In severe damage, fruit is distorted, stunted and unevenly grown. It is the only coconut fruit infesting mite in Sri Lanka that causes severe crop losses to the growers. Its damage can lead to small and deformed fruits (Alam and Islam, 2014) and premature fruit drop (Doreste, 1968; Nair, 2002; Wickramananda *et al.*, 2007). It can also cause reduction in copra yield (Hernández, 1977; Howard *et al.*, 2001; Moore and Howard, 1996; Ramaraju *et al.*, 2005; Muralidharan *et al.*, 2001; Alam and Islam, 2014), coconut fiber length and tensile strength (Naseema Beevi *et al.*, 2003) and yield of brown and white fibre from fruits (Kumar and Ramaraju, 2010).

Fernando and Aratchige (2010) reported that the palms infested by the coconut mite in Sri Lankan plantations varies between 2-100 per cent and as high as 86 per cent of the total fruits harvested (Wickramananda *et al.*, 2007). The percentage of small-sized fruits and deformed fruits are considerably higher in infested palms (0.72-25.5 per cent and 0.33-6.9 per cent respectively) compared to uninfested palms (<1 per cent) (Waidyarathne, unpublished data). An estimated loss of 15.8 per cent of total crop loss has been observed when the losses due to button and immature fruit fall, size reduction in the harvested fruits and fruit deformation were taken collectively (Wickramananda *et al.*, 2007). The rainfall of the same month and the previous month did not significantly affect the coconut mite densities; however, the drought length (*i.e.* the number of days without rainfall of >5 mm) affected the densities of coconut mite (Aratchige *et al.*, 2012a). Longer the dry period, higher were the coconut mite densities. In general, the peak densities were observed during February-March and June-September *i.e.* during the period of either decreasing or low rainfall and the populations of coconut mite remained low during rainy seasons (Aratchige *et al.*, 2012a).

Due to its concealed habitat, insufficient exposure of coconut mite to harsh environmental conditions, pesticides and natural enemies, management of this pest is difficult. Moreover, it is capable of breeding in extremely high populations establishing permanent infestations in new areas, mostly in population outbursts in a short time. Its inefficiency in host finding is compensated by its high reproductive rates and ability to find refuge in secluded habitat, *i.e.* under the perianth of the coconut fruit. Feasible application of control measures for this pest is also a constraint due to the tall stature of many commercially grown coconut cultivars. However, both chemical and non-chemical methods have been tested in many countries to manage the coconut mite.

Monocrotophos (Fernando *et al.*, 2002), NeemAzal (Wickramananda *et al.*, 2003), neem oil and garlic mixture (Anon, 2001) and a mixture of 30 per cent used engine oil in water, soap powder and wheat flour (Chandrasiri and Fernando, 2004) have been recommended as chemical control measures to manage the coconut mite in Sri Lanka. Though these chemicals were effective in controlling the pest, growers' acceptance was low due to practical difficulty in application of the chemicals and varying degree of control. An emulsion of 20 per cent vegetable oil and 0.5 per cent sulphur WP was found to be effective in controlling the coconut mite (Fernando and Chandrasiri, 2010). Spraying of this emulsion on the immature fruit surface resulted in mean mortality of 87 per cent and 98 per cent reduction in the coconut mite population, compared to the control palms within first 20 days after spraying. The spraying of this emulsion at 6-month intervals significantly increased the undamaged fruits and decreased the damaged, small-sized fruits in the harvest. Results of a cost-benefit analysis has shown that benefit: cost ratio varies between 0.56-4.15 suggesting that the spraying of the emulsion is profitable to the growers. Application of this emulsion was less effective on *Neoseiulus baraki* Athias-Henriot, the predatory mite of the coconut mite (Fernando and Chandrasiri, 2010). Based on these results, spraying of 20 per cent palm oil and 0.5 per cent sulphur in an aqueous emulsion has been recommended to control coconut mite. This is the most effective chemical control recommendation against the coconut mite.

Biological control of the coconut mite had drawn relatively little attention in the world until late 1990's (Moore and Howard 1996; Moraes and Zacarias, 2002). Since its detection in Sri Lanka and India in late 1990s, this area of research has been intensified in those countries. Later countries such as Brazil, Benin, Tanzania and Oman have also focused their research in this direction. In Sri Lanka, local and exotic predatory mites and an entomopathogenic fungus have been evaluated as biological control agents.

At the outset of the outbreak of coconut mite in Sri Lanka, two exotic predatory mites, *N. cucumeris* Oudemans and *N. californicus* McGregor were tested but they were found to be ineffective as they were unable to establish their populations in the field (Anon,1999).Later, another predatory mite, *Proctolaelaps bickleyi* Bram was also imported and tested which ended up in a failure due to its inability to creep under the perianth and predation on the local predatory mites (Anon, 2005).Therefore, research on biological control using predatory mites in Sri Lanka mainly focused on the local predatory mite, *N. baraki*, which is the most common predatory mite found in association with the coconut mite especially in the dry- and intermediate-zones of the country (Fernando and Aratchige, 2010). The key factors for selecting it as a potential predatory mite were its flat and elongated idiosoma with short distal setae and short legs (Moraes and Zacarias, 2002; Moraes *et al.*, 2004) enabling it to creep under the perianth, its close contact with the coconut mite (Fernando *et al.*, 2003; Aratchige, 2007; Aratchige *et al.*, 2012b) and its ability to feed and develop on coconut mites (Anon, 2003). Series of experiments were conducted in Sri Lanka to evaluate its bio-ecological aspects and potential to control the coconut mite (Fernando *et al.*, 2003, 2010; Aratchige *et al.*, 2008, 2010, 2012a, 2012b; Kumara *et al.*, 2014).

Population dynamics studies conducted in Sri Lanka shows that the fluctuation pattern of *N. baraki* differs spatially and temporally. The population densities of *N. baraki* are not significantly regulated by the amount but by the frequency of rainfall of the same month, drought length and the density of the coconut mite, one month prior to that of *N. baraki* (Aratchige *et al.*, 2012a). The authors have suggested that *N. baraki* populations are more influenced than the coconut mite populations by external abiotic factors probably due to more active movement of the former than the latter in search of food and shelter.

For testing of *N. baraki* for its potential as a predatory mite of the coconut mite, essentially a mass production protocol was sought. Except coconut mite, out

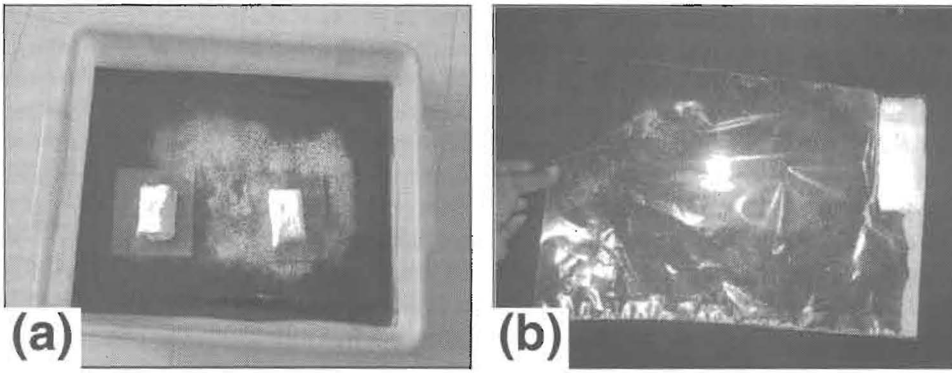

Figure 2.2: (a) Tray-type arena for the mass production of *N. baraki*, (b) Sachet-type rearing method of *N.baraki*.

of the several food sources that were tested (Fernando *et al.*, 2004; De Silva and Fernando, 2008; Anon, 2001, 2002, 2003) *Tyrophagus putrescentiae* Shrank (Acari: Ascidae) was more suitable (Fernando *et al.*, 2004). Therefore, *T. putrescentiae* was subsequently used in studies to develop mass rearing methods (Aratchige *et al.*, 2010; Kumara *et al.*, 2014) and in field releases (Fernando *et al.*, 2010; Aratchige *et al.*, 2012b). *N. baraki* can be mass produced on *T. putrescentiae* reared on a black polyvinyl sheet in tray-type rearing arenas (Aratchige *et al.*, 2010). Insect glue layer applied along the periphery of the polyvinyl sheet avoids the escape of the mites from the arena and protects the cultures from external contaminants. A glass sheet on a small piece of synthetic net and a piece of foam wrapped in a wet tissue on the glass sheet are also kept inside the arena to supply shade, oviposition sites and drinking water respectively. Rice bran and flour mixture (1:1) is sprinkled on the polyvinyl sheet and *T. putrescentiae* and *N. baraki* are mass produced on the same arena (Figure 2.2). A 240-fold increase of *N. baraki* is obtained from this method in 5 weeks (Aratchige *et al.*, 2010). Laborious nature of removal of the insect glue layer from the polyvinyl sheet is one of the drawbacks of this method which was excluded in the sachet-type rearing unit (Kumara *et al.*, 2014). In this method, *N. baraki* is mass produced on *T. putrescentiae* inside a two-ply polypropylene sachet, which contains rice bran and flour mixture (1:1) and a piece of wet tissue paper in a partially separated compartment. A 260-fold increase of the original population could be obtained from this method in 6 weeks (Kumara *et al.*, 2014). Using this method, approximately 2,000 sachets could be accommodated in an insectary room of 4 x 3.5 m^2 (air-conditioned, 25°C) which has 6 racks with 3 shelves of 2 m x 0.5 m x 1.5 m each (Figure 2.3).

The first attempt to evaluate the single release of *N. baraki* in controlling the coconut mite was reported by Fernando *et al.* (2010) in which a single inundative release of 10,000 *N. baraki* significantly increased its population and decreased the coconut mite population. During the post release period of 6 months, mean numbers of 8.99 *N. baraki* and 1264.77 coconut mites per fruit were observed in the released palms compared to the unreleased palms (6.19 *N. baraki* and 1815.0 coconut mites per fruit). However, the marked reduction in the coconut mite populations was not

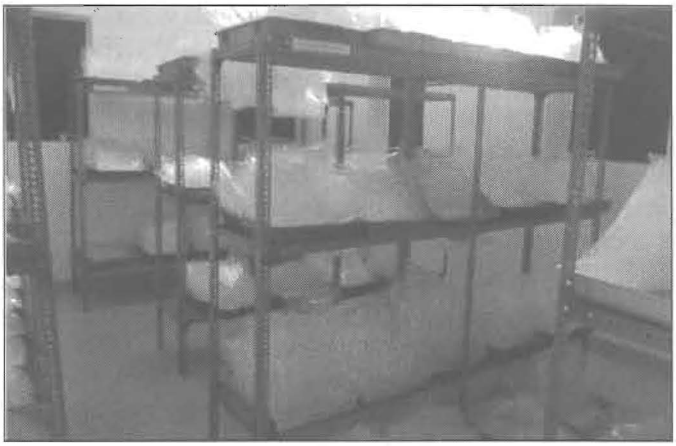

Figure 2.3: Mass Rearing Insectary Room of *N. baraki*.

mirrored in the reduction of the damage due to coconut mites. Authors suggested that multiple releases of *N. baraki* would be a better alternative due to the occurrence of continuous infestation of coconut mites in its several generations over a long period of 2-6 months on fruits.

Release of 5000 *N. baraki*/palm at 2-4 month intervals for 2 years on to quarter of a plantation of 5ac resulted in a higher percentage of normal-sized fruits at harvest (85.6 and 88.4 per cent in two released blocks compared to 79.1 and 80.1 per cent in unreleased blocks) and a lower percentage of small-sized fruits (13.3 and 10.1 per cent in two released blocks compared to 20.0 and 17.2 per cent in unreleased blocks) (Aratchige *et al.*, 2012b). Release of *N. baraki* in this manner has shown to be economically effective as it has resulted in benefit: cost ratio of 1.76-3.11 (Aratchige *et al.*, 2012b).

In Sri Lanka, release of 5000 *N. baraki* at 3-4 month intervals (depending on the rains) on to quarter of the coconut plantation at least for 2 years has been recommended to control the coconut mite (Aratchige *et al.*, 2012b) and this is the first recommendation of using predatory mites for the control of coconut mite in the world. The Coconut Research Institute of Sri Lanka conducts a national level project in collaboration with the Coconut Cultivation Board (CCB) and 2 state-owned private companies, Chilaw Plantation PLC. and Kurunegala Plantation PLC. and under this project,13 mass producing laboratories of *N. baraki* are being operated to supply *N. baraki* sufficiently to the growers. After commencing release of *N. baraki* from one laboratory managed by the CCB, a 35-43 per cent reduction in the rejected fruits in the harvest has been observed in 2013, 2014 and 2015 in one block of 10ac compared to 2010-2012 pre-release period (Wickramasinghe I, unpublished data).

The natural incidence of the *Hirsutella thompsonii* Fisher, an entomopathogenic fungus of coconut mite was low (Edgington *et al.*, 2008) and out of the isolates collected from different geographical regions of Sri Lanka, only four isolates, namely IMI 390486, IMI 391722, IMI 391942 and IMI 391723, performed better when the growth characteristics and sporulation in culture were compared. Isolate IMI

391722 outperformed the others showing the highest vegetative growth between 20-35°C and the second highest spore production at 15-35°C (Edgington *et al.*, 2008). The highest efficacy in reducing the pest population and the highest percentage of fruits with mycosis were achieved when two applications of spore suspensions of the above isolate were made at two week intervals on the five youngest coconut bunches (Fernando *et al.*, 2007). However, this effect was relatively short and the results were not consistent (Fernando *et al.*, 2007) and the use of *H. thompsonii* for the control of coconut mite was discontinued in Sri Lanka.

Variation in the varieties in responses to the coconut mite damage is one of the aspects that have been less studied in Sri Lanka and in other countries. Certain varieties have shown less damage by the coconut mite (Julia and Mariau, 1979; Schliesske, 1988; Suarez, 1990; Muthiah and Natarajan, 2004; Nair, 2002; Ramaraju *et al.*, 2002; Thirumalai Thevan *et al.*, 2004; Varadarajan and David, 2003; Moore and Alexander, 1990; Perera *et al.*, 2013; Mohan *et al.*, 2014). Preliminary study to investigate the differences between levels of tolerance in the varieties in terms of symptoms initiation, subsequent expression of symptoms, coconut mite population levels, distance between fruit surface and the perianth of the fruit and the crop loss due to mite damage revealed that the above parameters were least in Yellow Dwarf x Sri Lanka Tall hybrid (DYT) suggesting DYT as a putative tolerant coconut variety for coconut mite damage in Sri Lanka (Perera *et al.*, 2013). In a recent study, variety Yellow Dwarf showed the least damage with moderate coconut mite densities while the varieties Gonthambili and Ran thambili were moderately damaged by the coconut mite probably due to round shaped fruits that restrict access to coconut mites. Variety Ran thambili showed the least coconut mite densities while the variety Gonthambili was infested with a moderate coconut mite density. Sri Lanka Green Dwarf, followed by the Sri Lanka Tall variety were the most susceptible variety to the coconut mite damage (Aratchige and Perera, unpublished data).

6. Plesispa Beetle, *Plesispa reichei*

Plesispa beetle is a recent invasion into Sri Lanka and is believed to be an accidental introduction into the country (Anon, 1999). It was first reported in Sri Lanka in 1999 from a coconut seedlings nursery in Gampaha district in the Western Province (Anon, 1999). The infestation has expanded rapidly into many other coconut growing areas through transportation of infested seedlings (Suwandharathna *et al.*, 2011). It is one of major pests of coconut cultivation in Philippines, Indonesia, Thailand, Singapore and Malaysia (Sivapragasam and Hong, 2007). Both adults and larvae feed on the leaflets of unopened fronds in seedlings in nurseries and young plantations retarding the growth. The damage is observed as brown patches or streaks on leaflets when they are opened.

In order to understand the biology of plesispa beetle, research has been intensified in Sri Lanka to determine its development and life cycle (Kumari *et al.*, 2009; Suwandharathne *et al.*, 2011; Bentharage *et al.*, 2012). The incubation period of the eggs varied between 7 - 9 days at 25 -31°C; higher the temperature, lower was the incubation period (Suwandharathne *et al.*, 2011; Bentharage *et al.*, 2012). The hatchability of plesispa beetle eggs was 81 per cent (Kumari *et al.*, 2009) and it was higher when the eggs were laid on the spear leaf than on the other leaves (Bentharage *et al.*, 2009). Although the incubation period of eggs was not influenced by the maturity of leaves on which they were laid, egg production of females was increased when they were allowed to feed on mature leaves, *i.e.* first and second open leaves (Bentharage *et al.*, 2009). Authors have suggested that the nutritional differences in mature leaves might have contributed to the increased egg production on them.

Five larval instars of plesispa beetle have been reported (Bentharage *et al.*, 2012). Temperature has a significant effect on development of 2nd and 4th instar larvae, pupal period and the total larval period while 1st and 3rd instar larval development was not affected by the varying temperature between 25 -31°C (Kumari *et al.*, 2009; Suwandharathne *et al.*, 2011). The duration of the life cycle (egg to adult) was 39.0, 30.2 and 29.7 days at 25, 28 and 31°C respectively suggesting that the warmer temperatures favour the rapid development (Kumari *et al.*, 2009; Suwandharathne *et al.*, 2011). Irrespective of the instar, larval development was slower on spear leaves compared to the first and second open leaves (Bentharage *et al.*, 2012). Leaf area consumption by the adults is also affected by the leaf growth stage; adults collected from the field feed more leaf area when they were allowed to feed on second open leaves (Bentharage *et al.*, 2012).

Chemicals have been recommended to control plesispa beetles in coconut in Sri Lanka but economically and environmentally acceptable alternatives are being assessed to aid in the management. Classical biological control is being evaluated with exotic parasitoid (*Tetrastichus brontispae*) (Suwandharathne, 2013).

7. Future Challenges and Research Needs

Coconut is an inimitable part of the Sri Lankan society as it is a basic sustenance of oil and a source of milk, drink and fuel and a part of many cultural events in Sri Lanka. It also adds a scenic beauty to the golden beaches around the country which is attracted by both local and foreign tourists. It is also used as raw material for many industries such as fibre, charcoal, desiccated coconut, coir products, timber and handicrafts and an important foreign income generator. Pests are a major limiting factor of the production of coconut in Sri Lanka and their damages continue to persist with severe crop losses, regardless of the developments in the knowledge and applications of the control of pests of coconut. Many factors contribute to this, among which slow diffusion of technology contributes to insufficiency in timely application of control measures against the pests. In this regard, government intervention is necessary to strengthen the extension system of the coconut industry to disseminate the knowledge to the stakeholders on control of pests.

Pest management is always a high priority in coconut plantations. Integrated pest management of coconut needs decision making guidelines for the implementation of the most appropriate control strategies of the pest. This is in particular needed because coconut is a crop with a tall stature and therefore control of pests is always difficult with high costs. Compared to other crops grown in Sri Lanka, growers' direct involvement in coconut plantation management is lower and the plantations are mainly managed by caretakers. Majority of the coconut growers in Sri Lanka maintain small-scale plantations where they demand for more convenient and practical control measures for which new avenues should be looked into and existing recommendations are needed to be broadened and fine-tuned.

Rapid worldwide demand for organic coconut production has prompted Sri Lankan coconut growers more motivated to produce coconuts organically which has claimed for research-based information to address issues, including pest management, to develop the industry as a viable and sustainable entity. Though research-based information on pest management are lacking within the context of organic coconut cultivation per se, integrated pest management practices that have been developed for conventional coconut farming have provided the framework for pest management tools in organic coconut farming. However, more research is needed to fill the knowledge gap in certain areas in the pest management in organic coconut cultivation. Soil fertility management has always been claimed to be beneficial in reducing the pest damages and though it has been a widely studied area of research in coconut, it has not been tested within the context of pest management even in conventional coconut cultivation. Information on mulching materials that will deter the development of pest insects (plant materials with insecticidal properties, insect repellents) will also be useful in prevention of development and survival of pests on organic mulches, but this concept has not been tested in the coconut system. One major challenge faced by the organic coconut farmers and the researches is the unavailability of sufficient and effective biological control agents for some major pests such as red palm weevil, plesispa beetle and termites. Urgent attention is needed to identify and develop mass rearing and inoculation methods of biological control agents of such pests. Unavailability of sufficient information on botanicals for the control of coconut pest is also another issue in controlling the pests in organic coconut farming. Though research-based information are available on a broad range of botanicals with insecticidal and repellent properties, such products have not been tested for pests of coconut in organic farming. Extracts of neem (*Azadirachta indica*) kernels, milk weed (*Calotropis procera*), periwinkle (*Catharanthes roseus*), tobacco (*Nicotiana tabacum*) and spinosads (insecticidal agent obtained from *Saccharopolyspora spinosa*) may have great potential as botanicals for pest management in organic coconut farming but research are needed in this direction.

To improve the potency of pheromone traps, it is suggested to combine them with other different techniques and also to use them in area-wide programs in trapping red palm weevil and rhinoceros beetles which may require institutional/ governmental involvement in technology dissemination and resource supply and growers participation in executing control measures. However, the rationale for such programs should be based on sound scientific evidence on the effect of area-wide trapping pests on the damage reduction and thereby the crop loss, because the integration of different techniques of pest control and area-wide management program are often costly. This is one of the areas where sound research-based information are lacking. Research on pheromones of RPW, rhinoceros beetle and black-headed caterpillar have also been widened to identify suitable, cost effective dispensers and formulations of pheromones with emphasis on nanotechnology.

In rhinoceros beetle control using OrV and GMF, basic information on the density dependence of the biological control agents on effectiveness in controlling the pest needs to be meticulously studied because, it could be expected that in low populations of beetles, spread of the OrV and GMF in the beetle population to be low due to low contacts of infected beetles with the healthy ones. The dispersal capacity of the beetle is another consideration that is to be taken in to account when using biological control using the OrV and GMF because its behavior is expected to be different when host plants are readily available in compared to the situation where host plants are relatively less densely present. As evidenced by Zelazny *et al.* (1989), OrV isolates could differ in its virulence when using against the adults and larvae of rhinoceros beetle and this aspect needs to be seriously taken in to consideration if the virus is included in the integrated management program of the pest. For rhinoceros beetle, effect of mass trapping of adults via pheromones could be enhanced when combined with biological control agents. This is possible with auto disseminated traps where beetles are lured to traps with pheromone mixed with spore solutions of GMF (Anon, 2015).

Rhinoceros beetle damage could also lead to RPW damage as both pests coexist in many coconut plantations in Sri Lanka and that the adult female RPW lays eggs on wounds made by the rhinoceros beetle. Therefore, use of pheromone traps could target both pests at a time using their respective pheromones (Hallett *et al.*, 1999). However, this type of recommendation should be based on thorough investigation of the population dynamics and the flight activity of the two insects.

Combination of traps such as barrel traps filled with a breeding substrate and coupled with solar-powered UV LEDs (Moore, 2013 a, b; 2014), pan traps (Moore, 2014) and fishnet traps (Moore, 2014) are other options for trapping rhinoceros beetles and with some modifications could also be used for red palm weevil as well. The inadequacy of the effectiveness of natural enemies of many of the pests of coconut highlights the needs for expanding the scouting of natural enemies probably in the area of origin of the pest. Given the exotic nature of the plesispa beetle in Sri Lanka, classical biological control appears to be promising as natural enemies of the pest are implausible to occur in Sri Lanka.

Use of resistant host plants is not currently recommended against any coconut pests in Sri Lanka. Improved cultivars and their parent materials are being evaluated for resistant to coconut mite damage. However, it is intended to expand this area of research in to the other coconut pests as well. It is also envisioned to determine the mode of resistance with possible molecular background and to include such traits if available, in the coconut breeding program.

Growing coconut with lot of uncertainties due to changed pest scenario has generated the need for reliable and timely forecast of pests. Nevertheless, this need has not been adequately addressed and there is practically no organized system of forecasting pests of coconut or other crops in Sri Lanka. In this regard, comprehensive scientific information on variations in pest severity with fluctuations of weather parameters, extent of pest damages and their threshold levels and monitoring systems of pest advancements are not available for most of the pests in

Sri Lanka. This statistics would also provide baseline information for understanding the outbreaks of coconut pests in new areas.

Coconut-based agro forestry systems have great potential for supplying multiple benefits to the grower. One important consideration within the context of coconut-based agro forestry systems is the management of pests in the system (Aratchige, 2011). Pest management in an agro forestry system may be different from that in a mono-crop system as the interactions among the components in a former system are more complicated than in the latter system. This is one of the areas which has not drawn attention in Sri Lanka and therefore, needs to be studied in future.

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