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INAUGURAL LECTURE

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The Spider Mite Saga - Quest for Biorational Management Strategies

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Born in 1948 in Johor Bahru, Professor Dr.Yusof Ibrahim attended College of Agriculture, Malaya in 1967 and obtained a Diploma in Agriculture in 1970. In 1971 he left for California and obtained a Bachelor of Science in Entomology in 1973 from University of California at Davis. He continued his education at Pennsylvania State University at State College in 1974 and obtained a Master of Science in Entomology two years later. He was awarded a PhD. in Entomology (*Behavioural Toxicology*) in 1985 from University of Missouri at Columbia, USA.

Professor Yusof began his career as a lecturer at the Institute of Agriculture, Serdang in 1970 and was appointed the Farm Manager in 1971. In 1976 he began his service at Universiti Putra Malaysia as a lecturer at the Department of Plant Protection, Faculty of Agriculture. In 1993 he was promoted to Associate Professor and then Professor of Entomology 10 years later.

In 1980 Professor Yusof was elected the Vice-President of the Malaysian Plant Protection Society (MAPPS) and remained a council member till 1982. Besides being a life member of MAPPS, he is also a member of several professional associations, amongst which are Entomological Society of America (ESA) and International Society for Southeast Asian Agricultural Sciences (ISAAS). He was the Vice-Chairman of the organising committee for the First International Conference on Plant Protection in the Tropics (ICPPT, 1982). Since then he had served under various capacities in conferences organised by MAPPS, and co-edited 3 proceedings, the latest being The 4th Asia Pacific Conference of Entomology (APCE, 2001). He was a member of the editorial board for the Journal of Plant Protection in the Tropics for 10 years and an active reviewer for a number of agricultural and biological science journals.

He was an expert panel member in the joint committee between DBP and Universities for the Development of Scientific Terminologies in Bahasa Malaysia for Farm Management (Plant Protection); Jawatankuasa Penyemakan Maklum Balas Daftar Istilah Pertanian; Agriculture Dictionary; Encyclopedia for Science and Technology; and Sidang Ke-11 Majlis Bahasa Brunei Darussalam-Indonesia-Malaysia (MABBIM). In addition, he was a member in the Special Working Committee for Pesticide Packaging (SIRIM); Working Group on Effects of Pesticides on Natural Enemies & Beneficial Organisms (DOA); Main Committee for Pest Update (DOA); National Council for Biological Control (Insects and Mites); and Chairman for the Assessment Committee for Agricultural Science Secondary School, Form 4 (MOE, 2002-03).

In 1989 he was a visiting scientist at the International Centre of Insect Physiology and Ecology (ICIPE, Kenya). From1986-91 he was a team member in *Simulation and Systems Analysis for Rice Production* (SARP) project, a collaborative research of IRRI, the Research

Institute of Agrobiology and Soil Fertility (AB-DLO), Wageningen, and the Department of Theoretical Production Ecology of Wageningen University (TPE-LUW), The Netherlands.

Professor Yusof's involvement in research has covered areas in insect population ecology and pests and diseases of insects and spider mites and their management. He has over 80 scientific publications to his credit of which 37 were papers in refereed journals. He has written a book on insect pests published by DBP, two laboratory manuals on entomology, contributed a chapter in a book published by CABI (United Kingdom) and another published by Pudoc (The Netherland). His current interest involves preparatory works aimed at developing an IPM programme against the spider mite *Tetranychus urticae* Koch complex by employing predatory mites and biorational agents such as predator-friendly acaricides and environment-friendly entomopathogenic microorganisms under sheltered environment.

Professor Yusof was awarded Tokoh Pendidik (Faculty of Agriculture) in 1994, Anugerah Khidmat Cemerlang (MAPPS) in 1996, Anugerah Khidmat Cemerlang (UPM) in 1997 & 2000, and the Vice-Chancellor Fellowship Award (UPM) in 2002. He is married with 4 children and resides in Bandar Baru Bangi, a suburb of Selangor.

THE SPIDER MITE SAGA : QUEST FOR BIORATIONAL MANAGEMENT STRATEGIES

ABSTRACT

The losses that growers have to absorb due to spider mites can be very discouraging. In spite of the use of acaricides which has understandably been short-term, the loss incurred in the Cameron Highlands ranged between 10-50% annually. The spider mite is quick in overcoming practically all chemicals currently available in the market, thus new compounds have to be used incessantly. Such situations will enhance the potential for the development of genetic resistance. As complete elimination of the spider mite is almost impossible, biological agents can play a significant role in the reduction of mite population, even though they may not function as reliably as chemical pesticides in every situations. Information on the bioecological demographic performance of two indigenous predatory mite species has indicated that they are potentially effective suppressors of spider mite population. A programme of intermittent inundative release sufficiently enhanced by selective acaricide could form the basis for an integrated mite management (IMM) system. Additional microbial control agents in the form of sprayable entomopathogenic fungi indigenous to Malaysia are now available to complement the action of the predators, and can perhaps serve as a plausible alternative to unilateral reliance on chemical acaricides. Hence, an integrated management system to control spider mites can be put in place so that food crops free from pesticide residue can be made available to the consumers.

INTRODUCTION

A relatively small number of families of mites are pests on economically important crops. Among the most serious of these belong to the order Prostigmata under the families Eriophyidae, Tarsonemidae, Tetranychidae and Tenuipalpidae. They are rather tiny, rarely exceeding 0.8 mm in size. The location of the feeding damage on plants caused by the sucking mouthparts is the most important clue in determining the presence of these acarines. They mainly feed on leaves but sometimes damage specific plant parts such as cotyledons, fruits, flowers and shoot tips. Symptoms vary depending on the mite species, the characteristics of the leaves, the weather shortly after attack and the specific reactions of the plant to the attack. Hot and dry weather often intensifies the symptoms of damage. Most common damage is done from feeding on the underside of leaves producing characteristic small, light coloured spots or stipple patterns which on prolonged exposure will develop into irregularly shaped translucent specks that later coalesce to become clear patches.

Control effort in Malaysia is accomplished almost exclusively with chemical pesticides due to their purported effectiveness, low ratio of cost to potential loss and the current lack of economic control alternatives. However, intensive use of these acaricides also cause population resurgence when resistance develops amongst pest strains and important natural enemies are eliminated (Waage, 1989), hence inviting growers on the path of pesticide trademill (Hansen, 1987).

During recent years phytophagous mites, particularly the spider mite complex (Tetranychidae), and their predatory counterparts (Mesostigmata: Phytoseiidae) have attracted the interest of scientists from all over the world. However, prior to 1980 not much was known about these mites in Malaysia. Information was merely in the form of reports of incidences and damages on crops and ornamental plants. It is noteworthy to mention here that serious scientific research on spider mite and its biological control agents began only in 1986.

SYSTEMATIC POSITION AND TAXONOMIC CLASSIFICATION

From the phylum Arthropoda arises three major evolutionary representatives: the Uniramia of which insects belong to, the Crustacea where prawns and lobsters are grouped, and the Chelicerata which comprises the mites, spiders and the likes. The mites constitute a large group with more than 30,000 species have been described. Although majority are free-living, thousands of species are yet to be discovered. The mites lack the paired mandibles of the insects and the 2-paired antennae of the lobsters. Instead, the mite, placed under Acari or Acarina, being one of the eleven subclasses of Arachnida, possesses a paired chelicerae wh ich serve as the feeding organs. The movable digits of the chelicerae has been modified for piercing plant cells.

The term Acari means headless, i.e. "a" in Greek means without, and "kari' means head. So, contrary to popular belief, mites are not insects which have three body sections, ie. the head, thorax and the abdomen. The body is essentially made up of a ***cephalothorax,*** i.e. fusion of the head and the thorax, and the ***abdomen.*** Currently, seven orders of mites are recognised, namely:

Notostigmata (=Opilioacarida)
Tetrastigmata (=Holothryrida)
Cryptostigmata (=Oribatida)
Metastigmata (=Ixodida)
Prostigmata
Mesostigmata
Astigmata

Only the last three orders are of importance in agricultural crops while members of Metastigmata are ectoparasites on animals. Majority of the plant pests are from Prostigmata while some stored product pests are in Astigmata. The Mesostigmata contains most of the predatory mites although other less conspicuous beneficial species are also found in Prostigmata and Astigmata.

Due to the dwindling number of mite specialist, the taxonomic status of many tetranychid species are still confusing and unsolved. The taxonomy of the red spider mite, *Tetranychus urticae* Koch complex, is still unsettled and this is reflected aptly when it is still referred to as a complex species which bears 60 other synonyms in the literature (Boudreaux and Dosse, 1963; Jeppson *et al.*, 1975; Bolland *et al.*, 1998). Each of these names were described from different plant hosts or geographical regions of the world, hence the confusion in the nomenclature. In the past, acarologists and applied entomologists commonly referred the spider mite in question as *T. bimaculatus* Harvey and *T. telarius* (Linnaeus). Other synonyms include *T. altheae, T. multisetus, T. cinnabarinus* and *Eotetranychus cucurbitacearum.*

Recently, however, *T. cinnabarinus*, which is not found in Malaysia has been proposed as a separate species based mainly on some trivial differences in some morphological traits, genetics and geographical distribution. Recent publications have attempted to elevate the taxonomic status of *T. cinnabarinus* and recognised it as a separate species from the twospotted spider mite complex based on two minor traits, i.e. the semicircular body shape of the female and the rounded anterior angulation knobbed shape of the aedeagus of the male counterpart. However, as long as these mites are not reproductively isolated, i.e. they interbreed and produce fertile offsprings, they should still be recognised as the same species. Typically this strain is known with the concept that it is tropical whereby the population starts developing during the warmer months and then markedly declines during the cooler rainy seasons. New tools such as molecular techniques are being used now. Further details can be referred to in Krantz (1978) and Evans (1992).

DAMAGE AND IMPORTANCE

In Malaysia, the major plant feeding mites are the spider mites (Tetranychidae) and the broad mite (Tarsonemidae), although the false spider mites (Tenuipalpidae) and the gall mites (Eriophyidae) occur sporadically. The Bulletin No.153 (Yunus & Ho, 1980) produced by the Department of Agriculture listed 22 families of phytophagous mites comprising 45 species, eleven of which were tetranychids, one tarsonemid and four eriophyids. In addition five predatory phytoseiids were listed.

The tetranychids are widely distributed and commonly known as spider mites. The male and female sexes are common in most species of tetranychid mites. The male becomes attracted to the sex pheromone released by the pharate female deutonymph (chrysalis), and once arrested the male will guard her until corpulation. The females are reproductively arrhenotokous, parthenogenetically male producing whereby unfertilised eggs produce only male offsprings while fertilised eggs produce females. Mated females produce both males and females because not every egg receives a spermatozoon. The development of tetranychid mites takes place through the egg, larva (3-legged), protonymph, deutonymph and adult stages. Each nymphal stage has both the feeding and the quiescent chrysalis stage. They are exclusively phytophagous and many species are polyphagous in nature and are serious pests of agricultural crops including vegetables, ornamentals and fruits.

During recent years many species have assumed the status of major pest. Many feed on both leaf surfaces. On ornamentals the red mites, *Tetranychus piercei*, feeds on the lower surface whereas *Eotetranychus* sp. and *Oligonychus* sp. are always found on the upper surface of rose leaves. During feeding, mites puncture the parenchyma cells and the chloroplasts of the leaf epidermis with their needle-like chelicerae and suck the cell sap. This feeding activity reduces chlorophyll content and leads to formation of numerous empty cells at the site resulting in the formation of yellowish or brownish spots, and with extensive feeding by large number of mites will cause the leaves to appear yellow or brown. Heavy infestation reduces transpiration and inhibits photosynthesis. These leaves will eventually shrivel and followed with total defoliation of the plant. Such injuries are particularly economically destructive in ornamentals. The expansion of monocultures increases the potential danger of them competing with Man; a single crop culture provides uniform and extensive food supplies and with an unguarded contamination of the culture could easily lead to an explosive increase of the population. In cases of crops under protected agricultural systems with intensive cultivation practices have increased nutritive value and thus become especially vulnerable in a relatively dry environment.

Some species produce copious webbing. One such species is the glasshouse spider mite, ***Tetranychus urticae*** Koch complex, which is also known as the twospotted spider mite or the red spider mites. Spider mites are so named due to their ability to produce silken web. In Malaysia, there are two forms, the indigenous red spider mites and the invasive twospotted spider mites. Both forms look similar at the larval and nymphal stages, but unlike the red form which is completely red, the twospotted form bears two conspicuous spots on the dorsum when turning adult. They coexist in nature but the red form is the dominant race. In Europe, they are classified as host races since the red form is mainly on tomatoes and the green form is mainly on cucurbits (Gotoh *et. al.*, 1993). Their high reproductive potential and rapid development are the two main reasons why they are a very successful species. Their rapid development is a linear function of temperature, ranging at a diurnal temperature cycle of between 25-30°C which is close to what we have now in Genting and the Cameron Highlands.

Table 1 shows the comparison of their demographic parameters, especially R_o, r_m and λ, indicating that the twospotted form is reproductively superior and these are achieved within a short generation time (T) of two weeks; however, majority of the red form survive longer reaching median natural mortality (NM_{50}) after five weeks compared to just two weeks for the twospotted form (Ibrahim, 1997). They are able to produce up to 26 generations in the cooler highlands and at least 19 additional generations in the lowlands. The fecundity increases with lower relative humidity. A female can produce as many as 100 eggs throughout her life time of about 40 days. Their rapid development of less than two weeks in the cooler highlands and 10 days in the warmer lowlands has contributed to the high capacity of populaton increase and hence doubling the population in barely three days. As such their numerical increase is rather explosive. Growers must consider appropriate control measures within the first week of detection; if not the population will be allowed to increase unhindered at the rate of 1.33 times each day (r_m=0.286; $\lambda=e^{rm}$) and thus will continue to double every 2.4 days thereafter (DT=2.4). Hence if a mature female starts an infestation, the number of spider mites would be almost 55 times that of the initial population ($N_{14}=N_o e^{0.286*14}$) in just two weeks. As such they are among the most feared by growers and no doubt the most important pest mites of cultivated crops in Malaysia, especially those high value agricultural crops. Johnson and Lion (1991) reported

Table 1. Comparison of demographic statistics between the red spider (RSM) and the twospotted spider mites (TSSM).

Parameters	TSSM	RSM
Life span (days): female	56	53
male	29	34
Median natural mortality, NM_{50} : female	21st day	41st day
male	11th day	12th day
Ovipositional period, days	32	40
Average fecundity, eggs/female	29.2	89.4
Net reproductive rate, R_o	57.6	53.28
Generation time, T , days	16.5	23.5
Doubling time, DT , days	2.8	4.1
Intrinsic rate of increase, r_c	0.246	0.169
Finite rate of increase, l	1.279	1.184
Innate capacity for increase, r_m	0.286[b]	0.240[a]

[a] $r_m = r_c$ when $Se^{-xa} l_x m_x = 1$ was fulfilled, where $a = r_c$

that, contrary to other mite species, it has a low host specificity, infesting over 200 plant species, especially the economically important ornamentals such as orchids, chrysanthemum, carnations, dahlias, statice, peacock and roses, vegetables such as cucumbers, brinjals, tomatoes, chillies, lady's fingers and beans, and fruits such as melons and strawberries grown under protected environments such as in greenhouses, rainshelters and nurseries. The warmer and drier conditions under these shelters are the major abiotic factors that promote proliferation of these mites.

The eriophyids, commonly known as the gall mites in Malaysia, and also called rust, bud, blister, russet and velvet mites in other parts of the world are exclusively plant feeders. Typical members of this family have elongated worm-like body shape. Their legs have been reduced to two pairs only. The body size varies from as tiny as 0.1 to 0.5 mm. They have a simple life cycle (egg, larva, nymph, adult) but certain species have complicated cycles that include alternations of generations. Two forms are recognised; the *protogynes* consists of both sexes (tropical), while the other occurs in the temperate called *deutogynes* that overwinters as females only. Those that are of concern to us are the tiny gall-forming mites, worm-like and generally not visible to the unaided eye, and the tiny rust mites which feed and develop on citrus foliage and fruits.

Not much is known about the gall mites, *Eriophyes* spp. and *Aceria* spp., in Malaysia, however, they have been reported to form woody stem galls on chrysanthemums, round and finger or stringy galls on leaves of shade trees, thus affecting the aesthetic values.

The rust mites, *Phyllocoptruta oleivora* (Ashmead), are long wedge-shaped and yellowish measuring 0.1 mm long. They have been reported on the citrus (limau madu) in Terengganu, feeding and developed year round on foliage, but will immediately concentrate on fruits when available. Early damage on the exposed surface of fruit is evidenced by bronzing of the rind. Badly affected fruits do not develop normally and frequently exhibit fruit cracks. A heavily infested fruit displays a dull cloudy appearance and the heavy feeding destroys the rind cells leading to the characteristic russeting of fruits. Such fruits do not fetch good market price.

The tarsonemids, commonly known as the yellow tea mites in Malaysia or simply the yellow mite in the subcontinent or the broad mite for the rest of the world, has a tiny (0.25 mm) shiny translucent white to pale yellow oval body which can barely be seen with the naked eyes. The yellow tea mite *Polyphagotarsonemus latus* (Banks) is the most frequently referred tarsonemid species in South-east Asia (Ibrahim, 1996). Earlier this species was known as *Hemitarsonemus latus* Dutta. It has a worldwide distribution in the tropical and subtropical regions and, as the name suggests, it infests many ornamentals such as chrysanthemums and dahlias, fruits such as mangoes, papaya and citrus, and economic crops such as cucurbits, beans, tomatoes and most importantly chillies (Kalshoven, 1981; Perring and Farrar, 1986). Sixty families of plants have been reported as hosts for this polyphagous mite (Gerson, 1992). They also survive on some annual broad leaf weeds under shelter (Ibrahim, 1996).

The broad mite passes through four stages, i.e. egg, larva, nymph and adult in slightly less than four days (Ibrahim and Low, 1998). However, the larva undergoes a quiescent resting stage called the chrysalis. Table 2 shows the pertinent demographic statistics of *P. latus*. The overall survivorship of *P. latus* to adulthood is relatively moderate (>80%). Although hatchability does not usually exceed 85%, mortality is minimal thereafter. Median natural mortality (NM_{50}) is usually reached within two weeks by the males and about four days later by the females. Since high mortality occurs during the egg stage, control measures ought to be employed as soon as the broad mite is observed because the eggs and the immatures are more vulnerable and thus would greatly add to the destruction of the population. Since the number of eggs laid was found to be proportional to the female life span, further delays in applying control measures after the first week of their presence should be avoided. This is because the innate proliferating capacity for population increase ($r_m = 0.2925$) is high enough to serve as a warning for chilli growers to consider appropriate control measures within the first week of detection; if not the population will be allowed to increase unhindered at the rate of 1.34 times each day ($\lambda = e^{rm}$) and thus will continue to double every 2.4 days thereafter (DT=2.4). Hence if a mature female starts an infestation, the number of broad mites would be 60 times that of the initial population ($N_{14} = N_o e^{0.2925*14}$) in just two weeks.

Table 2. Pertinent demographic statistics of *Polyphagotarsonemus latus* on chilli.

Parameters	Values
Survivorship to adulthood	83%
Sex ratio (female bias)	3.4:1
Life span (days): female	2.8
male	9.9
Median natural mortality, NM_{50} : female	17th day
male	13th day
Ovipositional period, days	20
Average fecundity, eggs/female	15.9 ± 7.3
Net reproductive rate, R_o	11.89
Generation time, T , days	10.4
Doubling time, DT , days	2.9
Intrinsic rate of increase, r_c	0.2387
Finite rate of increase, l	1.2696
Innate capacity for increase, r_m	0.2925[a]

[a] $r_m = r_c$ when $\Sigma e^{-xa} l_x m_x = 1$ was fulfilled, where $a = r_c$

In Malaysia chilli is the crop most severely affected by this mite. Symptoms on chilli is confined to flower parts and young tender foliage, typically the downward curling of leaf margin which becomes wrinkled at the edges and bronzing of new leaves and distorted new shoots. Serious infestation will manifest curling and crinkling of leaves resulting in rosetting of the shoot followed by dieback. Attacks in the seedling stage prevent flower and fruit development. Starting at the tip, the plant withers and auxiliary buds are then produced which in turn are killed. Infestations in mature plants will cause excessive flower drops. The male has a strong front pair of legs that allows it to guard and carry female nymph, called preconjugate, of his choice and hold fast onto the female while mating. Quite often two or more males will wrestle for a female nymphal preconjugate. The process of wrestling is, however, non-violent since competing males are never seen to make physical contact except for occasional accidental bumps. The tug-of-war ends when one of the males succeeded in pulling the preconjugate away from the other males. The female corpulates only once in her life time, while the male remains sexually active, however, it would corpulate only with nymphal preconjugates or virgin females which are determined by the males through a five second premating ritual. Only fertilised eggs produce female progenies.

PEST STATUS OF TETRANYCHUS URTICAE

Three forms of the spider mite, *T. urticae*, are recognised worldwide, ie the tropical red form, and the temperate green and yellow forms of the twospotted spider mites. In Malaysia the red spider mite is the most abundant, both in the lowlands and the highlands, while the twospotted strain is not so widespread and is mostly in the cooler highlands such as Genting and Cameron Highlands. They have been reported on chrysanthemums, roses and strawberries. In the subtropical regions of the world the red form spider mite, specifically referred to as carmine spider mite, *Tetranychus cinnabarinus*, is more prominent during the summer months, thus in the subcontinent it is labelled as the tropical strain as opposed to the temperate twospotted strain. The latter strain turns completely red when overwinters or enters diapause, a form of dormancy whereby the mite goes through a state of physiological rest in order to facilitate survival during the cold winters in the temperate regions.

Damage to plants is effected in several ways, namely:

1. The piercing and sucking mouthparts destroy the parenchyma cells from the underside of leaves resulting in a stippling and speckling appearance.
2. The destruction of chloroplasts and closure of stomata lead to the reduction of transpiration and inhibition of photosynthesis, and consequently results in leaf chlorosis (completely yellow to brown) and defoliation.
3. The loss in yield starts when about 30% of the foliage is affected.
4. The aesthetic injury in ornamentals due to speckling and webbing (dirty plant).

The red spider mites feed mainly on the underside of leaf surfaces causing leaves to drop prematurely. This in turn results in reduction of current yield and the weakening of plants. The damages may also include specific plant parts such as cotyledons, fruits, flowers, fruit spurs and tips of shoots. In field crops such as beans and cucurbits, severe infestations can cause total defoliation and thus poor production. They have also been reported on oil palms, tea, coffee, cocoa, pineapple plantations and orchards such as durians, mangoes and citrus (limau madu and pomelo). The twospotted form is widespread throughout the world and are of continuous potential danger in many glasshouses in the temperate regions and the cooler highlands of the tropics. Often they are not readily detected and the appearance of the injury is usually delayed, a couple of days later, until the mites have moved to new plants, thus the true cause of injury is often discovered when it is already too late.

Its economic impact on crop production varies with the population densities, composition of stages of mites and the season it occurs. Usually the new vegetative growth is the most attractive stage, and since these mites are positively phototaxic, the new growths at the upper stratum of the plant canopy become most vulnerable. In Malaysia, economic loses on crops due to mite infestation are not readily available. However, Syed and Sivapragasam (2001) have reported economic loses on the yields of French beans, cucumbers and strawberries when infestation exceeded 30%, and this is in spite of the use of insectoacaricides which are understandably short-term in nature. In some cases infestation on roses and chrysanthemums resulted in loses reaching 100%. In the latter cases the flowers are generally meant for exports to oversea markets which require practically zero infestation. Other examples, such as in Java, total defoliation was reported in a cassava plantation (Kalshoven, 1981).

SAMPLING AND MONITORING

Adult spider mite is soft-bodied, characteristically possesses four pairs of legs, but unlike the adult the larval mite is a tiny wingless creature and only possesses three pairs (like insects) of legs. As such they disperse by ambulatory means such as by crawling, and aerial dispersion by balooning in the wind with the aid of silken threads as in the case of the larvae.

Several procedures are available for determining the abundance of the red spider mites. Surveys and regular visits are required. In the field a hand lens (10X) can be used to detect their eggs, larval and nymphal stages. For taxonomic studies and confirmation to species, male specimens are important, however, they are difficult to locate due to their small size and their scarcity in the population. In such cases species identification becomes difficult since majority are determined on their male characters only.

Population monitoring is a very important component of integrated mite management programme. Sampling of infested leaves for adults and juveniles is always expressed on per leaf or leaf area basis. When hazardous insectoacaricides are used, careful monitoring is required for an extended period to make sure about the presence of enough predatory activity. Continuous monitoring also helps in timing of the intermittent release of the predatory mites as and when infestation level attains the threshold incidence. This frequently saves application of acaricides and also from their associated ill effects such as residue and resistance problems.

Prior to 1980 there was no written report of the twospotted form in Malaysia. The initial detection of its presence was in 1985 in the strawberries grown in the hydroponic research unit, UPM, Genting Highland. My gut feeling is that the mite was already in Cameron Highlands much earlier through transportation of planting materials, especially those most valuable for shades, ornamental and agricultural purposes. Perhaps quarantine awareness was not at its highest then and this invasive form could have easily slipped through since its habit of living and ovipositing in secluded places has protected it against detection at quarantine check points.

CURRENT MANAGEMENT PRACTICES

The control of spider mites has relied almost exclusively on specific chemical or synthetic acaricides such as Dicofol, Propargite, Buprofezin, Aramite, Sulphenone, Ovex, Formetanate, Fenbutatin-oxide, Amitraz, Hexythiazox, and most recently Avermectin, due to their purportedly quick action, low ratio of cost to potential loss, and lack of economical alternatives. Together with organophosphorus and carbamate insecticides such as carbaryl, which I termed as insectoacaricides, they have not been able to achieve sustained suppression of the population, instead many other problems have appeared in the environment. Pyrethroids, the main culprits, and most recently Imidacloprid are such cases whereby the spider mite populations and their injuries have increased exponentially on ornamental plants and in orchards. The mites have been reported to have become less sensitive and studies, including from our laboratory in UPM, have ascertained that the mites seemed to be induced to leave the crop and disperse as a result of a seemingly repellent effect at sublethal dosages (Ibrahim and Omar, 1991). Amongst such effects are **walk-off** the leaves and down the stem and **spin-down** the leaves on silken thread to be blown away, termed as balooning, by the wind and subsequently dispersed. Overcrowding of mites may also occur and this is manifested by **hot spots** of swarms of mites on leaf tips and fruit tips.

The changing climatic conditions in the tropics and the concomitant rapid shift in agricultural practices to grow high value crops, such as in large scale monocultures without crop rotation has also worsen the situation. In the lowlands the situation is aggravated further when an infestation starts with crops grown under shades due to the dry surrounding. Often growers regulate the mite populations by successive applications of acaricides or insectoacaricides, however, their natural enemies are more adversely affected when these insectoacaricides are used. Consequently, an outbreak of the mites occurs.

Resurgence and secondary pest outbreaks have been commonly observed following insectoacaricide applications. Reduction of natural enemy populations is the major factor blamed for these phenomena. But an often overlooked factor which is partially responsible is the phenomenon of **hormoligosis** or **hormesis** whereby subharmful of sublethal exposure to the pesticide has increased the total fecundity. McKee *et al.* (1987) reported that a low flucythrinate concentration elicited immediate dispersal within 120 minutes of post-treatment and showed a trend toward increased fecundity, thus providing evidence that pyrethroid-induced mite population outbreaks can result from dispersal of healthy mites to areas of low competition. This pesticide-induced hormesis is very common in spider mites; not only that more eggs are produced, fecundity is also advanced to an earlier age due to accelerated maturation of immature stages. This often leads to the need for additional chemical treatment which often results in a spiralling increase in the use the pesticides, termed as the **pesticide syndrome.**

BIOLOGICAL CONTROL OF MITES

The red spider mite is quick in overcoming practically all compounds currently available in the market, thus new compounds have to be used incessantly. Even though chemicals appear to be a better control measure, several debacles may arise as the consequence of overdose or overuse. For instance, the natural ecology could be interrupted because the water run-off might carry the chemical compounds into rivers, hence marine life would be destroyed and environmental contamination could dangerously affect non-target organisms. Besides, the inundative use of these chemicals might bring about the accumulation of toxic substances in the food chain which eventually leads to the consumption by human, and this would impair our health or worse, death might occur, a situation termed as biological magnification. Such situations enhance the potential for the development of genetic resistance when acaricidal treatments are required to regulate the population throughout the growing season. It is thus desirable to minimise the use of or replace chemical spraying by biological control agents.

Knowing that all these problems may assume greater importance in the future, I have put unremitting efforts into my research that have focused on the practice of biological pest control, in this case the biological mite control. It involves the use and the manipulation of specially chosen living organisms to control the spider mite population. The organisms that I have been working with since late 80s are the predatory phytoseiid mites. There is currently a dearth of expertise on this important agents in Malaysia or even South-east Asian region, especially on the taxonomy, bioecology and management, and the adverse effect of chemical pesticides on the impact of natural enemies; if they are eliminated by pesticides the result will be pest resurgence. Also, very little is known on other biological control agents such as the microbial pathogens. In Malaysia, serious scientific research in crop protection using entomopathogenic fungi against agricultural pests only started in the early 90s with studies against cabbage caterpillars and other vegetable insect pests. By the year 2003 many of the important vegetable pest species from Lepidoptera, Homoptera, Isoptera and Coleoptera have been tested to be susceptible to various fungal isolates. Among the most significant finding was, however, the discovery that these so called living insecticides were also efficacious against the broad mite and the red spider mites.

Biological control agents : Predatory mites

Often, local growers regulate spider mite populations solely with chemicals and neglect the under-used predatory mites as agents of biological control. The role of these biological agents has now become paramount in view of the efforts to minimise exposure to these hazardous chemicals and to safeguard the environment. Phytoseiids are the best-known predatory mites and have been shown to have the potential for regulating mite pests at low densities.

In Malaysia two phytoseiid species have been studied; they are *Neoseiulus longispinosus* (Evans) (sn.: *Typhlodromus longispinosus, Amblyseius longispinosus, Amblyseius womersleyi*) and recently *Proprioseiopsis mexicanus* (Garman). Pertinent bioecological performance of these two species have been assessed and revealed to be competent predators of the red spider mites. Table 3 shows the demographic statistics of these predators. The overall survivorship to adulthood for both predators exceeds 90% with the female *N. longispinosus* taking only five days to reach maturity and lived for 30 days while *P. mexicanus* was even shorter with less than four days and lived for 39 days. Their median natural mortalities (NM_{50}) were, however, similar reaching in 22 days for the former and 21 days for the latter. With *N. longispinosus*, oviposition started by the second day after emergence while *P. mexicanus* only started to oviposit by the sixth day of emergence.

Table 3. Comparison of demographic statistics between *N. longispinosus* (NL) and *P. mexicanus* (PM).

Parameters		TSSM	RSM
Life span (days):	female	30	39
	male	36	33
Median natural mortality, NM_{50} :	female	22nd day	21st day
	male	26th day	16th day
Ovipositional period, days		28	11.4
Average fecundity, eggs/female		43.3	30.2
Net reproductive rate, R_o		36.7	22.8
Generation time, T , days		9	13.3
Doubling time, DT , days		1.7	2.9
Intrinsic rate of increase, r_c		0.40	0.24
Finite rate of increase, l		1.49	1.27

The pertinent life table parameters for *N. longispinosus* showed that its net reproductive rate (R_0) indicated an average female could produce 37 female progenies within a generation time (T) of nine days, and with a high r_m of 0.4 the population doubles in just 1.7 days (Ibrahim and Palacio, 1994). Values for *P. mexicanus* are, however, slightly inferior whereby the average female could produce 23 female offsprings within a generation time of 13 days, and with a lower daily maximum potential reproductive capacity (r_m) of 0.297 individuals the population would only double within 3 days (Ibrahim and Joseph, 2004). The mean generation time of nine days for *N. longispinosus* and 13 days for *P. mexicanus* was respectively 2.5 and 1.8 times shorter than the red spider mite. All these are desirable attributes of an efficient predator.

The functional response curves for both species are adequately described by the Holling's Type II model; the trend of prey consumption rate is density-dependent, rising curvilinearly in response to increase in prey densities and stabilises to a plateau reaching the prey threshold density or satiation point of 35-40 eggs/female predator/day (Ibrahim and Abdul Rahman, 1997) (Figure 1). The immatures are preferred over the adults due to ease of handling. A satiation point of 10 adult preys/predator seems to be the response level for both predatory species. Life table parameters revealed that the development and reproduction of N. longispinosus were slightly better when subsisted on the red spider mites than on twospotted spioder mites (Ibrahim and Seo, 1995). All the aforementioned statistics indicate that they are potentially effective predators capable of stabilising the prey-predator interaction, thus allowing their numbers to stay in synchrony with their host, bearing in mind that in the absence of the predators the red spider mite is capable of increasing almost 55 times that of its initial population in just two weeks. The gravid female is recommended for the initial introduction since it is more voracious, demonstrating a higher searching rate (a') with a shorter handling time (T_h) compared to the young female, thus would increase the probability of an early establishment (Figure 2).

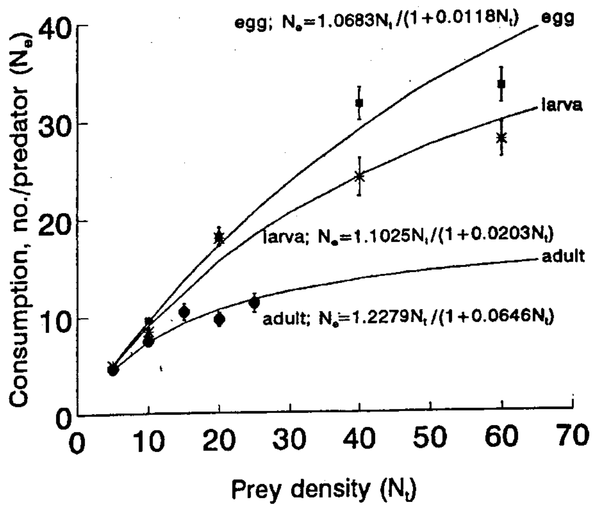

Figure 1. Functional responses of gravid female *N. longispinosus* on twospotted spider mite.

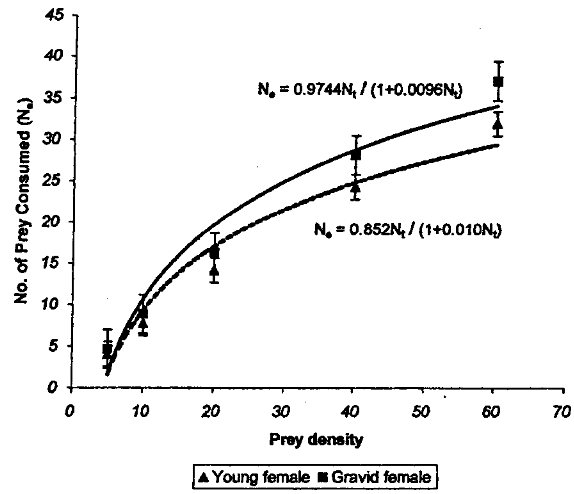

Figure 2. Functional responses of *P. mexicanus* on red spider mite.

Microbial control agents : Entomopathogenic fungi

In Europe, the awakened interest from researchers and growers towards microbial agents or entomopathogens has caused wide application of such control agents in agricultural and especially horticultural cultivations. Among these are the mitosporic deuteromycete fungi which have some advantages that make them unique among these entomopathogens. Besides killing their hosts by toxigenic action following oral ingestion, they usually invade their hosts directly through the integument using the germ tube of the germinating conidia. Once inside, it would grow profusely in the hemolymph, in which case death would ensue when all the host's tissues have been substituted by the mycelial mass, and as a result of starvation, physiological and/or biochemical disruption by toxins brought about by the fungus. The death of the host marks the parasitic phase of fungal development. The mycelia then continue to grow saprophytically, often producing antibiotics antagonistic to the intestinal bacterial flora. When environmental conditions become favourable, the fungus grows outward breaking through the host's integument and develops conidiogenous structures. In nature this may allow horizontal transmission of the fungal disease within the host's population. When conidia are produced within the host's cadaver, termed as resting spores, the fungus is able to survive through long periods of adverse conditions (Samson *et al.*, 1988). Therefore, fungal pathogens have potentials to be developed as suitable and safe alternative control agents.

In Malaysia, the first practical attempt of using fungus against insects was reported by Ooi (1979) when *Entomophthora sphaerosperma* was applied against the dimondback moth *Plutella xylostella*, however, this fungus could not perform effectively in the heavy rain and the heat (Ooi, 1981). The second scientific publication was only available 14 years later when Ibrahim and Low (1993) reported the successful use of microbial control agents against the diamondback moth, *P. xylostella*, with isolates of *Beauveria bassiana* and

Paecilomyces fumosoroseus. Since then many more research works in this field against other insects have been carried out (Ibrahim and Lee, 1996; Ibrahim and Hashim, 1998; Ibrahim and Tan, 1999; Ibrahim and Liu, 2001; Priyatno and Ibrahim, 2002a & b; Ibrahim and Yeong, 2002; Hashim *et al.*, 2002; Hashim and Ibrahim, 2003; Priyatno and Ibrahim, 2003). Table 4 shows the pathogenicity of some indigenous entomopathogenous fungal isolates against selected arthropod pests of crops of agricultural importance.

Table 4. Efficacy and potency of selected entomopathogenous fungal isolates on insects and mites of agricultural importance in Malaysia.

Fungi	Pests	% Mortality[a]	Slope ± SE	Dosage or EC_{50} (95% FL)[b]	LT_{50} (days)	References
Metarhizium anisopliae	Px	100	0.3 ± 0.05	0.07 (0.03-0.2)	1.5	Ibrahim & Liu (2001)
	Hu	100	0.4 ± 0.07	0.03 (0.02-0.3)	1.6	Ibrahim & Tan (1999)
	Cb	100	0.5 ± 0.04	0.2 (0.09-0.42)	2.2	Hashim & Ibrahim (2003)
	Ad	100	0.6 ± 0.06	0.73 (0.34-165)	na	Ibrahim & Yeong (2002)
	Ac	100	0.6 ± 0.11	0.07 (0.008-0.02)	2.6	Ibrahim & Ihsan (2003)
	Ag	100	0.8 ± 0.11	0.004 (0.0004-0.02)	2.6	Ibrahim & Ihsan (2003)
	Mp	94	0.3 ± 0.07	0.74 (0.015-23.4)	3.2	Ibrahim & Ihsan (2003)
	Ps	78	0.7 ± 0.14	14.7 (8.8-158.9)	2.7	Priyatno & Ibrahim (2003)
	Tu	98	0.4 ± 0.06	1.48 (0.69-27.2)[c]	1.7	Ibrahim (2003)
Beauveria bassiana	Px	100	0.4 ± 0.05	0.18 (0.07-0.52)	2.4	Ibrahim & Liu (2001)
	Hu	100	0.4 ± 0.04	0.12 (0.03-0.27)	2.7	Ibrahim & Tan (1999)
	Cb	100	0.4 ± 0.04	0.05 (0.02-0.12)	2.1	Hashim & Ibrahim (2003)
	Ad	100	0.6 ± 0.09	0.11 (0.09-0.92)	na	Ibrahim & Yeong (2002)
	Ac	54	0.5 ± 0.03	25.0 (14-53)	6.7	Ibrahim & Ihsan (2003)
	Ag	100	0.5 ± 0.11	0.03 (0.01-0.26)	1.8	Ibrahim & Ihsan (2003)
	Mp	76	0.5 ± 0.08	0.69 (0.13-3.28)	3.6	Ibrahim & Ihsan (2003)
	Ps	68	0.6 ± 0.06	33.2 (17-691)	3.1	Priyatno & Ibrahim (2003)
	Tu	96	0.4 ± 0.12	157 (33-2265)[c]	2.4	Ibrahim (2003)
Paecilomyces Fumosoroseus	Px	100	0.3 ± 0.05	0.03 (0.01-0.09)	1.3	Ibrahim & Liu (2001)
	Hu	100	0.4 ± 0.08	0.03 (0.007-0.34)	1.7	Ibrahim & Tan (1999)
	Cb	100	0.4 ± 0.04	0.02 (0.01-0.04)	1.7	Hashim & Ibrahim (2003)
	Ad	100	0.4 ± 0.05	0.07 (0.03-0.17)	na	Ibrahim & Yeong (2002)
	Ac	100	0.7 ± 0.14	0.03 (0.002-0.24)	3.1	Ibrahim & Ihsan (2003)
	Ag	100	0.9 ± 0.16	0.004 (0.002-4)	1.8	Ibrahim & Ihsan (2003)
	Mp	95	0.6 ± 0.08	0.13 (0.02-0.55)	3.0	Ibrahim & Ihsan (2003)
	Ps	64	0.5 ± 0.11	22 (1.5-749)	3.0	Priyatno & Ibrahim (2003)
	Tu	95	0.5 ± 0.27	34.9 (20-56)[c]	2.3	Ibrahim (2003)
Aschersonia placenta	Ad	100	0.6 ± 0.09	0.013 (0.003-0.04)	na	Ibrahim & Lee (1996)
	Cv	88	na	na	na	Ibrahim & Tang (1992)
	Au	86	na	na	na	Ibrahim & Tang (1992)

na not available
[a] max. dosage of 2×10^7 conidia ml^{-1}
[b] 1×10^5 conidia ml^{-1}
[c] 1×10^2 conidia ml^{-1}

Px = *Plutella xylostella*
Hu = *Hellula undalis*
Cb = *Crocidolomia binotalis*
Ad = *Aleurodicus dispersus*
Ac = *Aphis craccivora*
Ag = *A. gossypii*
Mp = *Myzus persicae*
Ps = *Phyllotreta striolata*
Tu = *Tetranychus urticae*

Research on phytophagous mites in Malaysia began to intensify in the 90s, however, quantitative data on the impact of some entomopathogenic taxa on phytophagous mites are only available by the turn of the century (Ibrahim, 2003; Ihsan and Ibrahim, 2004). Fungal pathogens have been shown to cause epizootics on mite populations in the US, Europe and Japan. Given the high humidity that we have in Malaysia I see no reason why mycopathogens cannot be as effective as has been reported elsewhere. The three main genera that I have been working with, ie. *Metarhizium, Beauveria* and *Paecilomyces,* have a worldwide distribution as members of the natural soil microflora. Entomopathogenicity of the fungal isolates in my collection have been examined and proven many a time to be bioefficacious against a great many varieties of insect pests of vegetables. These isolates have yet to be mass-produced for commercial formulation so that they can be employed as biological control agents on a large scale, probably not just targeted at niche markets. So a focused efforts are required in order to provide a fast track to implementation. Fungi are also particularly important for the control of acarines because viral and bacterial diseases on mites are rare and therefore their use can be assumed frivolous. Uniquely, unlike the baculoviruses (NPV, CPV or GV) and the bacteria such as the well known *Bacillus thuringiensis,* the entomopathogenic fungi do not have to be ingested by the target pest. They invade their hosts directly, with the help of cuticle-degrading enzymatic activities in the developing germ tube, through direct penetration of the integument, especially the intersegmental membrane, and the natural orifices such as the spiracles and anal opening. Therefore, they can infect non-feeding stages such as the eggs (ovicidal) and the pupae (pupicidal), as well as the sucking insects such as aphids, whiteflies, thrips and planthoppers which cannot ingest bacteria or viruses.

Records on previously described entomopathogenic taxa in Malaysia are scarce. So far, through studies conducted at UPM, tangible facts and proofs have been obtained on the bioefficacies of *P. fumosoroseus, B. bassiana* and *M. anisopliae* as microbial control agents to control the larvae of cabbage caterpillars, *P. xylostella, Crocilolomia binotalis* and *Hellula undalis,* the whitefly *Aleurodicus dispersus,* and the aphids *Aphis craccivora, A. gossypi* and *Myzus persicae.* In general, mortalities in excess of 90% were easily achieved at a dosage of as low as 10^7 conidia ml^{-1} in about three days, and a complete decimation was achieved in most cases at a dosage of 10^8 conidia ml^{-1}. Similar mortality percentages were obtained when these fungi were applied against the spider mites (Figure 3) and the broad mites. In fact half of the spider mites tested got infected in less than 48 hours and 50% mortality was achieved within three days. In the field chilli shoots infested with the broad mites recovered completely (Table 5) with zero mite population after four consecutive weekly sprays with laboratory formulated (wettable powder) mycopathogens (Figures 4 & 5), a result significantly similar to what was achieved with the acaricide Amitraz (Ihsan and Ibrahim, 2004).

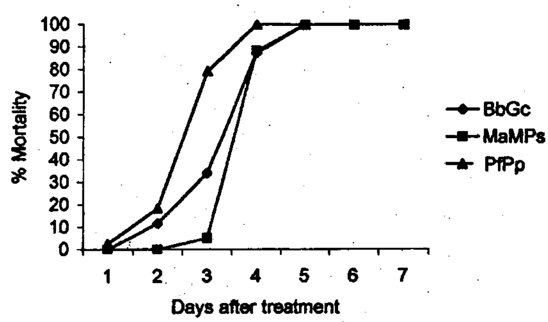

Figure 3. Mean percent mortality of female red spider mites upon exposure to 1×10^{8} conidia ml^{-1}.

Table 5. Mean percentage recovery of new chilli shoots seven days after final spray application.[a]

Treatments	Greenhouse	Field
B. bassiana	93.3 a	93.3 a
P. fumosoroseus	73.3 bc	83.3 b
M. anisopliae	46.7 c	-
M. anisopliae + *P. fumosoroseus*	80.0 ab	66.7 b
M. anisopliae + *B. bassiana*	80.0 ab	76.7 b
Amitraz	100 a	96.7 a
Control	0 d	8.3 c

Means within columns followed by the same letter are not Significantly different at P = 0.05 according to LSD.
[a] A total of 4 sprays spaced 5 days apart.

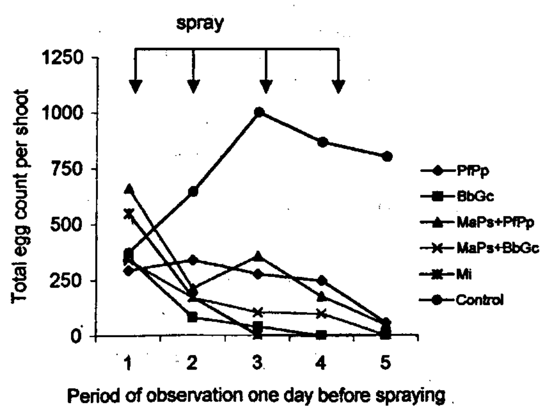

Figure 4. Number of broad mite eggs recorded at each period before spraying.

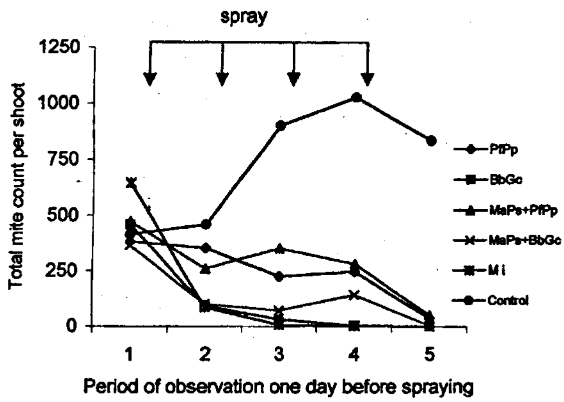

Figure 5. Number of adult broad mite recorded at each period before spraying.

INTEGRATED MITE MANAGEMENT

Can the red spider mite be managed? Major emphasis in the past has been placed upon insecticides in pest management programmes. Because the use of insecticides is at times costly, dangerous to workers, can disrupt the agroecosystem, can contaminate unintentionally and encourages pests to develop resistance, there is much interest in developing alternative management tactics. The combination of all possible pest management methodologies with state of the art modern contrivances have given birth to a more acceptable and environmentally friendly concept of pest management, ie. the IPM system, thus firmly placing biological control in a much more important role. However, integration of control tactics is only possible if natural enemies are least harmed by the insectoacaricides. Thus, identification of ecofriendly insectoacaricides, such as insect growth regulators, that are least hazardous to natural enemies is imperative in order to have a sound IMM system.

A programme of intermittent inundative release sufficiently enhanced by other environmentally friendly acaricidal agents, based primarily on the optimisation of selectivity, timing and application techniques, could form the prerequisite for an integrated spider mite management system. But, of course, the application of naturally occurring resistant or selectively bred resistant or genetically engineered resistant natural enemies, when available, would be the best option. Results of a study on the sublethal exposure of *N. longispinosus* to abamectin indicated that the longevity and fecundity of the predator were not markedly affected and the overall impact appeared moderate (Ibrahim and Tan, 2000) thus suggesting that abamectin could be used selectively to play a complementary role rather than antagonistic or even destructive in developing a sound IMM system. In theory, when abamectin acts to reduce abundance of the spider mite so as to fall within the range of density dependence of the predator with a Type II functional response, then the outcome should be beneficial in lowering the spider mite density further.

However, a unilateral reliance on the predatory mites alone cannot provide a complete protection from the spider mites. More often than not, the predators are usually effective in suppressing some, but not all, of the spider mites on the crop. Additional biological control agents may have to be made available to supplement the action of the predators. To this end, the fungi *Metarhizium anisopliae, Beauveria bassiana* and *Paecilomyces fumosoroseus* which have been found to be pathogenic against the red spider mites would fit perfectly into the management system. These fungi inflicted 100% mortality on the red spider mite at concentrations of 10^8 conidia ml^{-1} four days after application In fact, *Metarhizium* took <1.0 day to achieve 50% infectivity while *Paecilomyces* took 1.2 days and 1.8 days for *Beauveria*. Egg mycosis reaching 40% was, however, achieved only with *Metarhizium*. Interestingly, none of these fungi caused infection to both the predators, *N. longispinosus* (Ibrahim, 2001) and *P. mexicanus*, even after exposures to 10^8 conidia ml^{-1} for four days. Then, can plants use these entomopathogens as bodygards? Yes is the obvious answer.

CONCLUSION

Synthetic chemical insectoacaricides have been the mainstay of spider mite control for many years. However, present day agricultural practices have moved cautiously towards lesser dependency on these chemicals and alternative forms of control which are biorational in nature are beginning to emerge. Compounds such as abamectin and growth regulators which are effective at very low dosages have presented little hazard to beneficial predatory mites. Some of the "home-grown" mycopathogens formulated at UPM are about to enter the final phase on the R & D chain. The impetus towards mass production and the eventual positioning of mycoinsecticides as a complementary tactic in the overall IPM system could be accelerated with the financial support from the private sector. The need for environmentally friendly approach using microbial control agents is currently being assumed only by the bacteria *B. thuringiensis*, and certainly mycoinsecticides have a complementary role to play in the near future. The request for organic farm produce is one of the indications of the growing awareness of our consumers for chemical pesticide-free food crops.

I can say with full confidence that the technologies necessary for an effective integrated management system of the spider mites are now available.

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