Session 10A

Developments in Crop Protection, Including IPM Strategies, in Modern Horticultural Crop Production Systems 1

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Platform Papers:	10A-1 to 10A-3
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Trends in integrated pest management in the USA and Asia for vegetable production

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Vegetables are the fastest expanding crop sector in the world. The expansion of vegetable production in China has been particularly significant at almost 6% per year over most of the last 20 years. In 2005, world production of vegetables was 970 million tons with the top three producers being China (479 million tons), India (89 million tons) and the US (41 million tons), with many vegetables being consumed near where they are produced, especially in China and India. There is also considerable movement of vegetables on the world market, involving fresh and processed vegetables. The EU, followed by North America and Japan, are the world's most important fresh produce import regions. Countries vary in their standards of acceptable pest management practices and this can affect imports. Vegetables are high value commodities with high cosmetic standards. Traditional synthetic pesticides remain the dominant method for controlling weeds, diseases and insects to ensure these high standards. There is, however, increasing pressure to reduce the amount of pesticides used in vegetable production and this has created new challenges to growers as well as new opportunities to differentiate their products and increase their profits. This has led to a suite of terms for production practices, including organic, biodynamic and IPM. One unintended consequence of these attempts to differentiate production systems is that the consumer has become confused by the meaning and/or implication of these terms.

An overarching system that strives to reduce the use of traditional pesticides is integrated pest management (IPM). IPM uses a diversity of tactics to manage pest populations. These tactics include cultural management, host plant resistance, biological control, area-wide management, and the judicious use of pesticides. The goal of IPM is to grow high quality produce with minimal impact on human health and the environment, while providing a healthy economic return to the grower. Adoption of IPM practices has dramatically reduced pesticide inputs in many vegetable crops. Considerable worldwide attention is currently being paid to organic agriculture, which we consider a part of IPM since it shares many of the same goals and practices, although there are important differences. The market for organic agriculture is increasing at a rate of 20 % per year, but still has only a 3 % market share. Whole Foods Market is currently the largest retailer of organic foods with over 155 stores in North America and the UK. However, Walmart, the world's largest food retailer, is currently ramping up efforts to increase sales of organic foods. This is significant since Walmart generally sells to lower income clientele than Whole Foods Market.

Organic producers must follow specific practices that do not allow the use of synthetic pesticides or genetic engineering, although pesticides that have been derived from 'natural sources' can be used. Generally organic growers place more emphasis on pest avoidance through practices such as crop rotation, trap cropping, improved soil health and other tactics and these may lead to lower pest pressure. When a spray treatment is warranted, organic farmers often have very few pesticide options. For disease control, the available options, such as sulfur, copper and bicarbonate compounds, have variable efficacy depending upon the pathogens. Weed management in organic vegetable production relies on crop rotations, cultivation and other practices (e.g. flaming, hand weeding) since available organic-approved herbicides have generally low efficacy and high cost. For insect management, options are improving but are still relatively limited and expensive. The common ≥ 20 % higher price for organic vegetables may help justify higher production costs, but these price differentials are decreasing with the increasing supply of product. While IPM and organic growers may share much of the same philosophy about agricultural production and many of the same practices, the main differences in available technology between IPM and organic agriculture are that the latter does not allow synthetic pesticides or genetic engineering. However, the environmental and food safety consequences of this decision are a continuing topic of debate.

The use of genetic engineering for pest management, although not allowed in organic production, has grown tremendously throughout the world with over 10 million farmers growing crops on over 100 million ha in 2006 (http://www.isaaa.org/). However, for control of vegetable pests the area is quite small. Sweet corn has been engineered to express the Cry 1A(b) protein from the bacterium *Bacillus thuringiensis* (Bt) for control of caterpillars. Although very effective, it constitutes <5 % of the area grown to sweet corn in the US. The other transgenic vegetable grown in the US is squash that is resistant to a suite of viruses. It has been widely adopted in some states and the national net benefit was estimated to be $22 million in 2005 (http://www.ncfap.org.).

India and China are the key countries that are developing biotech vegetables for pest management. The first is the use of eggplant engineered to express Cry 1Ac to control the eggplant fruit and shoot borer in India, Bangladesh, and the Philippines (http://www.absp2.cornell.edu/). In Asia, spraying for this insect accounts for 24 % of the total cost of production, as farmers spray an average of 80 times over the 7-month cropping season. This excessive pesticide use threatens the health of farmers and consumers. Mahyco, a hybrid seed company based in India, has developed Bt eggplant and is working in a private-public partnership with national and international university partners to release plants as hybrids for higher-end farmers and open pollinated lines for resource-poor farmers. A socio-economic assessment estimated that Bt eggplant has the potential to benefit 700,000 farmers in India, Bangladesh, and the Philippines. The second project involves a private-public partnership that focuses on dual-Bt gene technology for cabbage and cauliflower for control of the diamondback moth in India and Africa (http://www.cimbaa.org/). In this project Nunhems Seeds is working with universities in the US, UK and Australia to ensure that the plants are deployed in a responsible fashion.

India and China have 37 % of the world's population. The emergence of biotech vegetables in these countries will have a large influence in the rest of the world. Whether results from these countries will increase its adoption worldwide will depend on technical, regulatory and social issues. The EU is likely to be slow to adopt biotech vegetables for pest management, largely due to political and social issues. Meanwhile traditional pesticides will continue to be the main strategy for most production systems. IPM and organic practices for pest control will evolve. However, until the price of organic products is reduced, they will continue to be reserved for higher-end, more affluent markets.

IPM in horticultural crops in 21st century Europe

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The practice of IPM in horticultural crops in Europe in the last half of the 20th century has primarily consisted of fine-tuning the use of pesticides to avoid unnecessary applications. This has led to benefits for growers, consumers and the environment. Many of the fundamental tools for this practice, the synthetic pesticides, are rapidly disappearing from the European market. At the same time, consumers are making clear choices for produce that is not treated with these pesticides. Most of the new pesticides that have appeared in the last decade, and pesticides currently under development, are less effective and/or less long-lasting in the field. These factors have been a driving force in the development of new methods of approaching pest problems in horticultural crops. There is little indication that any method alone will solve pest problems in a cropping situation.

Both new and innovative methods and tried-and-true methods are receiving much more attention. Crop rotation, one of the oldest methods for reducing pest problems, has become a much more common practice in horticultural crops, with the benefits in reduction of pest populations that this brings. In the heyday of chemical fertilizers and pesticides, crop rotation was not very common outside of organic farming. Other methods based on host plant/non-host plant interaction, such as intercropping and trap planting, are being investigated as further means of reducing pest attack.

Microbial control is beginning to make inroads into production of horticultural crops, both as "living pesticides" and through conservation biocontrol. *Bacillus thuringiensis* is so commonly used that it is often forgotten that it is a microbial agent. Research on fungal agents for control of insect and mite pests, as well as plant diseases, has increased to the point where most research centers for plant protection in Europe have some activity with beneficial fungi. The bacterial metabolite spinosad has been registered, or registration is pending, for use as an insecticide in several European countries. Fungal metabolites are under investigation for various uses, including insecticidal properties.

Novel methods of application of beneficial fungi are being explored. Auto-dissemination, where the pest insect is exposed to spores of an insect pathogenic fungus and then returns to the habitat where it interacts with others of the same species, is one method. Another, similar method, is the use of honeybees or bumblebees to spread beneficial fungi that attack pest insects or hinder development of plant diseases. The best example of the latter is the prevention of grey mould in strawberries by spreading beneficial fungi with honeybees.

Botanical insecticides such as neem and garlic are being produced for commercial use. With the disappearance of chemical insecticides from the market, even growers who practice conventional farming have shown an interest in these materials.

Physical barriers that prevent insect pests from getting to the crop are under development and are being used in practice. The best known of these are 'floating' row covers or fleece, but several more long-lasting covers are now available. These have been developed to prevent attack from specific pests, while causing minimal changes to the microclimatic under the cover.

Exclusion fences are an innovative means of preventing certain pests from reaching the crop, while allowing full access for field workers and machinery. The principle behind exclusion fences is that some key pests fly close to the ground in their search for host plants. The vertical barrier, combined with a barrier at the top of the fence, keeps the pests from reaching the crop. This method has gained popularity in recent years. It is being used against root flies, especially in brassica crops, but it is also being tested against other pests, such as the black vine weevil in strawberries.

The shift from the chemical paradigm to innovative alternative methods for controlling pest problems will continue in the years ahead. In principle, IPM has always included the use of available methods to keep pest organisms at an acceptable level. In practice, IPM has until recently mostly entailed using the methods and information available to limit unnecessary applications of pesticides. IPM in horticultural crops in Europe in the 21st century will entail a realization of the original principles. That is, not just the efficient use of chemical pesticides, but all rational methods will be considered for incorporation into IPM strategies.

Using plants to reduce pest insect populations in horticultural crops

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The several disadvantages of complete reliance on insecticides to control phytophagous pest insects have led to considerable research into alternative methods of insect control. These include methods of biological, microbial and physical control. The practical success of such techniques depends on the combination of insect, crop and environment that is targeted, but their commercial success depends also on the cost of implementation.

Plants, in the broadest sense, offer a number of opportunities for pest control, several of which are relatively cheap, 'environmentally friendly' and do not require registration. Perhaps the most obvious approach is to breed or engineer crop plants that are resistant to one or more pest insects. There have been some notable successes, and the main disadvantage, provided the crop is commercially acceptable, is the possibility that certain pest insects may be able to overcome host plant resistance. There are obviously ways of making the breakdown of resistance less likely.

Whilst the means of pest insect control is contained within the resistant plant itself, there are several other pest management techniques where different species of plant are grown within, or close to, the crop. Three of these techniques, trap cropping, companion planting and the use of wild flower strips to encourage natural enemies, are being investigated currently in the UK with the aim of reducing the numbers of pest insects in field vegetable crops. This research has been stimulated by the interest of both organic and conventional growers, wishing to incorporate such techniques into their IPM strategies.

A trap crop consists of plants that are grown specifically to provide an alternative source of food and/or oviposition sites for pests, in an attempt to reduce damage to the main crop. The pests that are arrested by the trap crop may then be destroyed or the trap crop and pests may be destroyed together. The plant species used for a trap crop must be a preferred host of the pest species targeted and trap crops are often grown as borders surrounding a main crop or as strips within it. Although the use of trap crops has been investigated quite widely, there are relatively few examples world-wide (about 10) where trap crops have been used in a commercial situation (Shelton & Badenes-Perez, 2006). Just over half of these examples are in 'horticultural' crops. The limitations of trap crops include their species-specificity, their relatively high cost in terms of loss of land, logistical complications and a lack of consistency. Recent work in the UK has focused on the control of brassica pests (*Delia radicum*, *Plutella xylostella*, *Phyllotreta* spp.) with trap crops and has been concerned mainly with the behaviour of the pest insects concerned.

In contrast to the plants used in trap crops, a companion plant is not a host of the pest species targeted. Many studies have shown that growing crop plants in close proximity to certain non-host companion plants reduces colonization by pest insects. Companion plants are usually interspersed with the main crop, rather than being grown as borders or strips. Under-sowing and intercropping are other forms of companion planting. The terminology used depends on the nature of the non-host plants (whether cropped or not) and their physical distribution (broadcast or in rows). A number of researchers have developed hypotheses to suggest why fewer pest insects are often found on crop plants grown in the presence of companion plants. Our recent research has indicated that the presence of alternative green surfaces, even those made of green card, interferes with the host plant selection behaviour of pest insects, thereby reducing the probability that they will settle on a host plant to feed or lay eggs. Contrary to expectation it appears that the companion plants do not have to act as deterrents or repellents to phytophagous insects. Indeed phytophagous insects are often arrested by non-host companion plants and spend a considerable time inactive on their foliage (Finch *et al.*, 2003). Our current project is focusing on the potential of companion plants to reduce colonization of cauliflower crops by *D. radicum* and one of the key objectives is to develop a system where inter-specific competition between crop and companion plant is minimised. In some circumstances, trap crops and companion plants have been deployed together in a so-called push-pull strategy. The most successful push-pull strategy, and the only one used in practice currently, is for the control of stem borers in maize and sorghum in Africa (Cook *et al.*, 2007). In this approach, stem borers are 'repelled' from the main crop by non-host intercrops and are 'concentrated' on attractive trap plants.

There is considerable interest in increasing plant diversity around and within field crops to enhance the performance of natural enemies. Although habitat manipulations such as wild flower margins have been investigated as suitable methods for increasing biological pest control in arable crops, the concept has not been tested fully, and there is little information on such habitat manipulations in horticultural crops. The overall aim of a new project at Warwick HRI is to demonstrate whether habitat manipulations such as wild flower refuges (blocks or strips containing plants such as poppy, buckwheat, tansy, chickweed, field scabious) will increase biological pest control of aphids in field grown lettuce.

All three approaches described above offer possibilities for pesticide-free insect control in horticultural crops. However, there are likely to be increased production costs attached to all of them, whether through the loss of productive land to trap crops or wild flower refuges or the loss of yield through increased inter-specific competition between a crop and its companion plants. However, the main criterion, at least in the UK, will be the level of pest control achieved and the quality of the harvested crop. At present, much more research is required to understand insect behaviour, and to determine whether such control methods can ever be sufficiently effective, either alone or in combination with other techniques, to be incorporated into commercial production systems.

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Area-wide pest management of fruit flies in Hawaii

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Background

Although scientists in Hawaii developed most of the technologies to combat accidental fruit fly outbreaks on the US mainland (e.g. California and Florida), these technologies were never packaged and transferred to Hawaiian farmers. The Hawaii Fruit Fly Area-Wide Pest Management (AWPM) program was designed to transfer these technologies to Hawaiian farmers and residents. In 1999, USDA-ARS initiated the Hawaii AWPM Program to suppress fruit flies below economic thresholds while reducing the use of organophosphate insecticides.

The program integrated biologically-based pest technologies into a comprehensive management package that was economically viable, environmentally sensitive and sustainable.

Technologies included:

1) field sanitation;
2) protein bait sprays;
3) male annihilation with male lures, and, if needed
4) augmentative parasitoid releases;
5) sterile insect releases.

In cooperation with the University of Hawaii, Hawaii Department of Agriculture, industry, and growers, we secured special local needs registrations for agricultural chemicals, implemented a fruit fly IPM extension educational program, developed site specific implementation plans and initiated trapping, sanitation and control measures within defined areas on Hawaii, Maui and Oahu Islands. Outreach programs were recently completed on Kauai, Lanai, and Molokai Islands. The AWPM program has been adopted by 2,540 cooperators, on over 607 farms encompassing 6,383 ha throughout the State.

Impacts

An economic analyst estimated the industry benefit of the AWPM Program to be $3.5 million in 2007. The internal rate of return (IRR) was calculated to be 28%. Using the AWPM program rather than conventional chemical pesticides, growers reduced fruit fly infestation from 30-40% to less than 5%. Within some of the demonstration sites, growers have begun growing crops they had previously abandoned due to fruit fly damage. California and Florida have also shown a keen interest in the program. California alone would suffer a $1.4 billion annual loss in export sanctions, treatment costs, lost markets, and reduced crop yields if the Medfly became established. Development and application of environmentally friendly area-wide fruit fly controls, as done in the Hawaii AWPM program, are of critical importance to keeping the mainland US free of the same fruit flies already established in Hawaii.

Unique to the Hawaiian AWPM program has been development of international collaborations. There have been close interactions with officials and researchers from many other countries, including Taiwan, the People's Republic of China (PRC), Australia, French Polynesia, Fiji, Guam, the Commonwealth of the Northern Mariana Islands, Mauritius and Reunion. Taiwan has been at the forefront of adopting the technologies that were implemented in Hawaii. For example, the Taiwan Agricultural Research Institute has initiated a program that includes: 5% of Taiwan's land, 172 cooperating towns and villages, and 149,713 ha involving 449 districts. The Taiwan AWPM program is now larger in scope than the Hawaii program. Similarly, through a partnership between Hawaii and French Polynesia, introduction of the wasp, *Fopius arisanus* (Sonan), improved fruits by as much as 75%.

This international technology transfer effort will not only help the countries affected, but will help protect American agriculture from the impact of devastating fruit fly invasions. The program has received seven major awards for different technology transfer activities.

Environment friendly methods to control olive fruit fly in Albanian organic olive orchards

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Introduction

Olive production in Albania is a leading industry that contributes to local economic development and enhances the quality of life of the community. Albania is a traditional exporter of olives and olive oil, and pests are the main constraint to production. Olive fruit fly (*Bactrocera olea* Gmelin) is the major insect pest. It causes serious damage to the fruits and reduces the quality of the oil. In the past, olive fruits were treated with large quantities of broad-spectrum insecticides. During recent years in Albania, chemical sprays have not been widely used and most groves now have viable populations of parasites and predators of black scale, a resource that should be conserved. At present, attempts are being made in Mediterranean countries to introduce new approaches such as the integrated pest management (IPM) practices that have been found useful for control of the olive fruit fly.

The usefulness of these practices needs to be tested in Albanian organic olive groves and if found to be effective, they will reduce pesticide residues in olive products and will allow successful biological control of black scale. In this paper we report the results obtained from the evaluation of an IPM package to control olive fruit fly during the years 2000 - 2003, which consists of an innovative combination of three different techniques:

- A specific monitoring system using pheromones for the olive fruit fly;
- The so-called 'Attract and Kill' method, which involves the use of pheromones and food attractants;
- Cultural practices, such as early harvesting of olives to prevent heavy attacks of olive fruit fly.

Results and discussion

Monitoring of olive fruit fly

Trap catches indicated that the olive fruit fly population varied through the year. The first flies appeared during May and June. Low numbers of olive fruit fly were observed during the hot and dry summer months, and the mean catch was never greater than 20 flies/trap. From the end of August, and during the autumn, olive fruit fly numbers increased due to favourable weather conditions.

Application of the 'Attract and Kill' method using Eco-Traps

The efficacy of the 'Attract and Kill' method was compared with the standard control method, i.e. bait sprays and chemical control applied to the ground. The Eco-trap contained 100 g ammonium bicarbonate salt, and, on its surface, 0.019 % w/w deltamethrin. A pheromone dispenser containing 80 mg of the major pheromone compound (1.7 – dioxaspiro{5.5} undecane) was fastened externally.

During the course of this research, the 'Attract and Kill' method reduced olive fruit fly infestations significantly. The results obtained up to the end of November, both in isolated and non-isolated olive groves, showed that one killing device per tree provided adequate protection on late ripening crops, especially in years when the density of the olive fruit fly population was low. For that reason, curative treatments with insecticides were not required to keep the fly population and fruit infestation at low levels. Good results were obtained also using one Eco-trap on every other tree in olive groves with a low or medium-sized olive canopy. During the harvest period, the olive fruit fly infestation was at an acceptable level.

In particular, good results were obtained in non-isolated olive groves where the 'Attract and Kill' method was applied using one Eco-trap per tree but only in September. No significant improvements were recorded when the Eco-traps were used twice (in June and in September). In the former case, the cost of the treatment was 50% lower.

Olive harvest timing

Early harvesting of the olives has proved to be a useful cultural method that contributes to the integrated control of olive fruit flies. Early harvesting prevents fruits from being available for attack during periods when peak numbers of olive fruit flies are active, whilst maintaining the yield and quality of the oil. As olives mature, both the quality and content of the oil increase. Depending upon the olive variety, the harvest period in Albania usually occurs in late November, when numbers of the olive fruit fly reach their most dangerous level. One of the options that was taken into consideration was to harvest olives before olive fruit fly infestations increase.

Based on data obtained from experimental work during 2000-2003, the most appropriate time to harvest cv Frantoi is 10-20 October. For cv Kalinjoti, the optimal time for olive oil accumulation is reached on 10 November, and this was not increased by harvesting later (20 November, 30 November, etc). A relatively high level of olive fruit fly infestation was observed after 20 November. The olive oils made from these fruits were analyzed at the Chemiservice laboratory (Monopoli, Italy), accredited by IOOC. The olives harvested between mid October and early November were rated as extra virgin, whereas the mid November sample was rated as virgin.

Conclusions

Application of the "Attract and Kill" method in olive groves indicated that this technqiue has the potential to replace, or reduce substantially, insecticide treatments for the control of olive fruit fly *(B. oleae)*.

In years when the population density of the olive fruit fly is low, and in isolated olive groves, the application of one trap per tree maintained the olive fruit fly infestation at low levels. Timely harvesting can be used to manage olive fruit fly infestations and provide a high yield of high quality olive oil. Harvesting olives in mid October to early November (depending on the cultivar) can produce Extra Virgin olive oil.

Development and validation of IPM technology in cauliflower

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Introduction

Cauliflower is one of the important crucifer vegetable crops grown extensively in India. It occupies an area of about 0.25 million ha with a production of 4.44 million t and a 5.2% share of vegetable production, ranking first in world production. The problems of indiscriminate use of chemical pesticides on vegetable crops are now widely recognized. They include resistance to pesticides, pest resurgence, pesticide residues in food, human and environmental hazards and harmful side effects on beneficial insects. To overcome the problems created by chemical-based conventional agriculture, implementation of integrated pest management (IPM) is considered to be a sustainable remedy, not only for pest mitigation, but also for a sustainable farming system as a whole.

Materials and methods

In the year 2006-7, field experiments were conducted at three locations in the village of Palari in the Sonipat District of Haryana State. Cauliflower was transplanted in the first week of July and harvesting started in the first week of September, continuing until mid October. At each location, the experiments used paired treatment comparisons to compare an IPM system with a conventional, non-IPM, system. The treatments tested at each location were: (a) an IPM module synthesized on the basis of available information from the literature, (b) a conventional system *vis a vis* farmers' practice (FP), using agronomic factors and methods of pest control commonly practiced by the local farmers. The IPM module comprised a soil application of *Trichoderma harzianum* at 2.50 kg/ha, application of neem cake at 50 g/m^2, soil solarization, treatment of seed with *T. harzianum* at 4 g/kg seed, seed bed sowing, seedling dips of *T. harzianum* at 4 gm/l, using Chinese cabbage as a trap crop, monitoring *Spodoptera litura* using pheromone traps and the need-based application of neem seed kernel extract (NSKE) 5% after 10-15 days, cartap hydrochloride after 15 to 25 days, quinalphos after 30-35 days, rimon 10 EC after 50 days, and *Spodoptera* NPV after 60-70 days. Hand picking of larvae and egg masses of *S. litura* (after transplantation) was validated. Counts of the major pests were conducted on 100 cauliflower plants from each of the IPM plots at 10 day intervals from the first fortnight of July until the plots were completely harvested. The numbers of insecticide sprays, the amount of insecticide and the various IPM inputs used during the growing season were recorded for each plot. The marketable yield of cauliflowers per plot was recorded at harvest time.

Results and discussion

Pest incidence

The crop was transplanted in the first week of July. *Plutella xylostella, S. litura, Hellula undalis, Bagrada hilaris* and *Crocidolomia horticola* were among the insect pests, and stem rot and *Alternaria* leaf spot were among the diseases observed infesting the crop. Larval *S. litura* were recorded soon after planting, but numbers of larvae were higher from the last week of August through to November. *Hellula undalis* was observed at the seedling stage, from the first week of July, and continued to increase until mid-August, which coincided with the drier period of the season with little rainfall. Captures of adult male *S. litura* were observed as soon as the pheromone traps were installed and continued to rise until the crop was harvested. Peak captures were obtained between the first week of August and the third week of September. Captures were low from mid-September to the last week of October and after that, higher numbers of moths were captured from the first week of November. No male *P. xylostella* were captured in pheromone traps and no caterpillar damage was observed throughout July to October, apart from one or two plants that were damaged during August. Among the diseases, 2-3% plants had stem rot before curd and head formation and 3-4% plants had *Alternaria* leaf spot as the curds matured, but the impact on yield was negligible.

Yield and economics of the IPM module validated in early cauliflower

Yield data were recorded for early cauliflower in the IPM and FP (non IPM) fields (Table 1). The mean yield of curds was 60.5 dt/ha in the IPM fields, compared with 56.5 dt/ha in the FP fields. This showed that the IPM treatments of five sprays, comprising *Spodoptera* NPV, novurolon, quinalphos, cartap hydrochloride and NSKE gave a 6.7% increase in yield compared with farmers' practice, where 10 sprays of highly toxic insecticides were applied. The total cost of cultivation using IPM was Rs 42,250/ha, which was lower than the estimated cost of cultivation (Rs. 47,500) in the non IPM plots, emphasising the importance of IPM practices. The application of IPM generated higher returns; values being Rs 181,500 per ha for IPM and Rs 168,000 per ha for non-IPM plots. The net returns were also higher at Rs 139,250 per ha with IPM, and Rs 120,500 per ha with non IPM systems. The adoption of IPM yielded higher benefits of Rs 18,750 per ha, and the cost-benefit ratio was 1:4.29 in IPM, while it was 1:3.53 in FP plots (Table 1). The results show that IPM has the potential to replace chemical pesticides without increasing the cost of cultivation. It also gave higher yields, with the added advantage that it has no adverse effect on the environment, natural enemies or human health. Birthal (2003) also reported IPM to be as, or more, profitable than chemical pesticides. The IPM module gave higher economic returns.

Table 1. Economics of early cauliflower production (Rs/ha) in IPM and FP (non IPM) plots

	IPM	FP
Total cost (all inputs)	42,250	47,500
Mean Yield (dt/ha)	60.50	56.50
Total Returns	181,500	168,000
Net Returns	139,250	120,500
Cost Benefit Ratio	1:4.29	1:3.53

Value of cauliflower: Rs.3000/dt (approx)

The total costs included: the labour costs for land preparation, nursery sowing, transplanting, fertilizer application, hand weeding and pesticide application, and material costs such as seed, pesticides, biocontrol agents, fertilizers etc.

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Grape vine moth in Albania

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Abstract

Among a number of insect pests of vines in Albania, the common grapevine moth, *Lobesia botrana* is predominant. Other insects cause only sporadic damage. *Lobesia botrana* was found in all types of vineyards, producing three generations a year, and with a high population density in years with moderately hot summers and high humidity. The most severe infestations generally occurred in vineyards with extended training systems and on compact cluster cultivars. Limiting factors were high summer temperatures and mortality of over-wintering pupae due to numerous parasites and predators. Damage varied with cultivar, compact-cluster cultivars being the most attacked. Cultivars with loose grape clusters were less susceptible.

The intervention thresholds established from controlled experiments and damage evaluations took into account the dependence of treatment effectiveness upon cluster conformation as well as cultivar susceptibility to attack. For the less susceptible cultivars, sampling was done at a larval infestation level of 10% to 15% of clusters. For cultivars with compact grape-clusters, not only did the intervention threshold have to be lower (5% to 10%), but also the decision to intervene required much more urgency. Pheromone traps helped considerably to minimize pest management costs. Furthermore, their use made it possible to intervene against heavy attacks at exactly the right moment, particularly important in the case of compact cluster cultivars.

Introduction

Grape moth is the main pest of Albanian vineyards, which are one of Albania's most important agricultural sectors. The area devoted to vineyards is increasing every year.

Materials and methods

The experiment was carried out in the area of Lushnje. The cultivars 'Merlot' and 'Shesh i zi' were selected for the experiment. The adult flight of *Lobesia botrana* was monitored by setting up four pheromone traps. The numbers of adults captured were recorded every week. Assessments of the second and third generations were carried out by periodic sampling of the larval stages on bunches of grapes.

Evaluation of damage by the second and third generations forms the basis of the economic threshold. For the less susceptible cultivars, sampling was done at a larval infestation level of 10-15% of clusters. For cultivars with compact grape clusters, not only did the intervention threshold have to be lower (5% to 10%), but also the decision to intervene required much more urgency. By using pheromone traps, the treatment period was varied according to the insecticide used. For *Lobesia botrana,* 100 clusters per cultivar per generation were examined.

Results and discussions

On the basis of the pheromone trap captures, *Lobesia botrana* completes three generation per year in Albania (Table 1). The first generation lasted 78 days in 'Merlot' and 71 days in 'Shesh i zi'; the second and third generations lasted 36 days. First generation damage does not usually require insecticide treatment. The methods used in cases where chemical control is necessary are varied according to the cultivar and compounds.

Table 1. Average weekly number of *Lobesia botrana* in 'Merlot' and 'Shesh i zi' cultivars

Number of *L. botrana* in pheromone traps			
Counting date	Merlot	Counting date	Shesh
13.04.2006	2.5	14.04.2006	14.5
20.04.2006	3.5	21.04.2006	13.0
27.04.2006	9.3	28.04.2006	9.8
04.05.2006	15.5	05.05.2006	13.0
11.05.2006	18.8	12.05.2006	28.0
18.05.2006	24.0	19.05.2006	14.5
25.05.2006	22.3	26.05.2006	8.5
01.06.2006	32.5	02.06.2006	12.5
08.06.2006	11.3	09.06.2006	9.0
15.06.2006	7.8	16.06.2006	5.0
22.06.2006	5.3	23.06.2006	1.3
29.06.2006	1.3	29.06.2006	9.3
06.07.2006	4.3	05.07.2006	13.0
13.07.2006	10.0	12.07.2006	17.0
20.07.2006	17.0	19.07.2006	19.5
27.07.2006	13.0	26.07.2006	8.5
03.08.2006	4.5	02.08.2006	3.5
10.08.2006	7	09.08.2006	8
17.08.2006	9	16.08.2006	15
24.08.2006	15	23.08.2006	13.5

Toxicity of pesticides to the citrus leafminer and its parasitoid *Ageniaspis citricola* evaluated to assess their suitability for an IPM program in citrus nurseries

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Introduction

Citrus nursery production systems are especially susceptible to leafminer damage because seedlings and young trees flush nearly continuously, and their ability to store nutrients is limited. Citrus nursery trees are regularly treated with pesticides to protect them from the citrus leafminer (*Phyllocnistis citrella*), other arthropod pests, and diseases. Information about which pesticides are compatible with the encyrtid wasp *Ageniaspis citricola* Logvinovskaya (Hymenoptera: Encyrtidae) and other natural enemies was seen as a priority in the development of an IPM program. We report the toxicity of chemicals commonly used in nurseries (insecticides, acaricides, fungicides, and foliar fertilizers) to adults and immature stages of the citrus leafminer and its parasitoid *A. citricola.* Several bioassay methods were used because a single technique may give misleading conclusions. Because it is difficult to compare different products, different rates, and different application methods, we developed three indices to assess the results of bioassays, which tested the lowest recommended field rate. The Selectivity Index rated the toxicity of each pesticide to the parasitoid *A. citricola,* and the Efficacy Index rated their efficacies in controlling the citrus leafminer. An overall estimate of the suitability of each pesticide for a citrus nursery IPM program was made by combining these two indices in an IPM-Compatibility Index.

Methods

The relative toxicities of pesticides to citrus leafminer (*Phyllocnistis citrella*) and its parasitoid *Ageniaspis citricola* were compared by several bioassay methods. A clip-cage bioassay measured survival of adults exposed to fresh residues at 0.25-times (0.25×), 0.5×, 1×, and 2× the lowest recommended rate of each pesticide, a water control, and 24- and 48-h aged residues of oil at 1.5% (1×) rate. A one-species cylinder bioassay was used to test the effects of pesticides on immature stages of the citrus leafminer after treating young citrus trees with the same rates of pesticides (except for avermectin, tested at 0×, 0.01×, 0.025×, 0.05×, 0.1×, and 0.25× rates). A sublethal rate of petroleum oil (0.4 %) was added as an adjuvant in some treatments. The effects of pesticides on immature stages of *A. citricola* were determined with a two-species cylinder bioassay after treating young citrus trees with the same rates as above. An index of IPM compatibility was developed based on the efficacy of the pesticide in controlling the leafminer (or other pests) and its selectivity to the parasitoid at the lowest recommended field rate (0.25× the field rate for avermectin).

Results and discussion

Petroleum oil. Oil proved to be an IPM-compatible product. While 1-h old residues at the lowest rate were toxic to both leafminer and *A. citricola* adults in clip-cage tests, aged residues (24- and 48-h old) allowed survival of adults of both species. In cylinder bioassays, as oil rates were increased, fewer leafminer pupae developed successfully. High levels of parasitism were obtained at all residue rates tested.

Neem-based products. Azadirachtin, formulated as Align, did not affect survival of either pest or parasitoid adults in clip cages. In the cylinder bioassay, when this product was combined with oil, no, or very few, leafminer or parasitoid pupae were produced, and few leafminer larvae survived. However, the few pupal chambers found were heavily parasitized by *A. citricola*. In the cylinder bioassay where azadirachtin was sprayed without oil before the citrus leafminer or *A. citricola* oviposited, similar results were obtained. Azadirachtin alone had no effect on survival of adult leafminers or *A. citricola*. This formulation did reduce the number of leafminer pupae in cylinder bioassays, but the percentage parasitism of surviving leafminer hosts was high.

Insect growth regulators. Diflubenzuron (Micromite) did not affect survival of citrus leafminer or *A. citricola* adults, as expected for a chitin synthesis inhibitor, because it affects the ability of immatures to molt. Diflubenzuron residues, tested both with and without oil, reduced survival of leafminer pupae and larvae, but the parasitism of surviving hosts by *A. citricola* remained high. The juvenile hormone analog fenoxycarb (Eclipse) did not affect adult citrus leafminer or *A. citricola* survival in clip cages.

Imidacloprid. Sprayed imidacloprid (Provado) eliminated all *A. citricola* adults at all rates tested in clip cages, but only slightly decreased survival of leafminer adults. No cylinder tests were conducted with foliar sprays of this product due to its high toxicity to adult parasitoids, and this application method is not recommended for use in citrus nurseries.

Avermectin. Recommended field rates of avermectin (Agri-Mek) do not seem appropriate for an IPM program in citrus nurseries. Avermectin reduced survival of both the leafminer and *A. citricola* adults in clip cages at all rates tested, except for the leafminer at 0.25× the lowest recommended field rate. In the cylinder bioassays, avermectin was an effective contact pesticide, and no leafminer or *A. citricola* immatures survived at rates as low as 0.1× in tests using either avermectin + oil or avermectin without oil.

Ethion. This organophosphorous insecticide and acaricide decreased survival of adult leafminers and killed all *A. citricola* adults in the clip-cage bioassays.

Fish oil. This organic foliar fertilizer (Hydrolyzed Fish Emulsion) reduced survival of leafminer adults at the lowest recommended field rate and higher, and of *A. citricola* at all rates. Fish oil did not act as an insecticide on immature leafminers under our laboratory conditions. In the cylinder tests, high numbers of citrus leafminer and *A. citricola* pupae were produced, and the percentage parasitism was high.

Copper hydroxide. This fungicide (Kocide 101) allowed high survival of leafminer adults in clip-cage tests, but reduced survival of *A. citricola* adults at rates higher than 0.5× the lowest recommended field rate. Based on clip-cage data alone, copper hydroxide was rated as moderately selective to the parasitoid and thus compatible for an IPM program.

Conclusions

Azadirachtin (Neemix) + oil, diflubenzuron (Micromite) + oil, fenoxycarb (Eclipse) + oil, and oil alone were classified as IPM-compatible insecticides. Sprays of azadirachtin (Align) + oil, neem oil (Neemgard), and drenched imidacloprid (Admire) were ranked as a semi-compatible insecticides. The fungicide copper hydroxide and a fish oil-based foliar fertilizer (Zapata HFE) were considered compatible. Avermectin (Agri-Mek) + oil, ethion (Ethion), and imidacloprid (Provado) applied as a spray were IPM-incompatible insecticides. The products should be tested under field conditions to confirm these ratings.

Bioefficacy and toxicity of some new and novel insecticides against some lepidopteran insect pests of vegetables

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Pests are the main limiting factor for vegetable production in India, amongst which lepidopteran pests cause a significant amount of damage. Vegetables are some of the most profitable crops and farmers everywhere feel the need to protect such high value crops from any type of damage caused by insect pests. They often use synthetic insecticides indiscriminately, and insect resistance to insecticides is very common in the tropics. Lepidopteran pests such as diamond-back moth (DBM) on cabbage (*Plutella xylostella*), fruit borer on tomato (*Helicoverpa armigera*), pod borer on chilli (*Spodoptera litura*), and shoot and fruit borers on brinjal (*Leucinodes orbonalis*) and okra (*Earias fabia*), are among the major pests of vegetables.

To control lepidopteran pests efficiently, some new pesticides, with novel modes of action, have been developed recently. To determine the effectiveness of the new pesticides compared with traditional chemicals, five field experiments were done on tomato, cabbage, chilli, brinjal and okra over two seasons. They compared nine pesticides (flubendiamide, pyridalyl, spinosad, emamectin benzoate, *Bacillus thuringiensis*, novaluron, methoxyfenozide, indoxacarb, and mixed formulations of chlorpyrifos and cypermethrin) with untreated controls. All other agronomic practices were standard, and a blanket spray to control sucking pest insects and mites was applied when necessary.

Our results (Table 1) showed that flubendiamide, spinosad and pyridalyl were highly effective in reducing the damage caused by diamond-back moth on cabbage, fruit borer on tomato, pod borer on chilli, shoot and fruit borer on brinjal and shoot and fruit borer on okra, and led to increases in yield. Novaluron was most effective against pod borer on chilli, closely followed by spinosad, flubendiamide and pyridalyl. In the case of fruit borer on tomato, spinosad was the most effective. Shoot and fruit borers on brinjal and okra were also controlled effectively by flubendiamide, spinosad and pyridalyl. The other chemicals, indoxacarb, emamectin benzoate and methoxyfenozide, and *Bacillus thuringiensis,* also performed well in reducing damage and increasing yield. *Bacillus thuringiensis* and methoxyfenozide were, however, less effective against shoot and fruit borer on brinjal and okra compared to other chemicals.

The new pesticides, with novel modes of action and high selectivity, were highly effective against lepidopteran pests. They are safer to non-target organisms and quickly degrade to non-toxic products.

Population fluctuations of *Aphis craccivora* and *Liriomyza trifolii* and their endoparasitoids on certain faba bean varieties

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Abstract

Infestations by *A. craccivora* (Koch) and *L. trifolii* (Burg) and their associated parasitoids were studied on four faba bean cultivars (Misr 1, Misr 2, Giza 40 and Giza 429) at Shandawel, Sohag Governorate during 2004/05 and 2005/06. Infestation rates of both pests were greatest in February and March. The susceptibilities of the cultivars were ranked (in both months) according to the mean numbers of aphids per plant: Misr 1 (40.6), Misr 2 (42.6), Giza 40 (54.2) and Giza 429 (58.7). Infestation levels for the leafminer were: Misr 2 (18.2%), Giza 429 (19.8%), Misr 1 (23.9%) and Giza 40 (26.1%). *Aphis craccivora* was parasitised by three species of hymenopterous parasitoid: *Lysiphlebus fabarum*, *Aphidius matricariae* and *Trioxys sp.* Three species of parasitoid were also associated with *Liriomyza trifolii*: *Diglyphus isaea* Walker, *Pnigalio* sp. (Eulophidae) and *Opius* sp. (Braconidae). These parasitoids reached their maxima during February and March, when levels of parasitism were 21.1% and 17.2% for aphids, and 12.8% and 13.1% for leafminer.

Introduction

Faba bean, *Vicia faba,* is considered to be one of the most important crops in Egypt, being used for human food as a fresh vegetable or as a dry seed. It is attacked by several pests, both in the field and when stored. *Aphis craccivora* (Koch) is considered to be one of the most important insect pests attacking faba bean in the field (Abdel-Samad, 1996). Factors affecting aphid infestations have been studied, by several authors, including planting date (El-Heneidy et al., 1998); sowing date (Loss et al., 1998); and population dynamics and weather conditions (Sharma and Yadav, 1994). The present study aimed to shed more light on infestation rates of *A. craccivora* and the leafminer *Liriomyza trifolii,* and their associated endoparasitoids in fields of four cultivars of faba bean.

Results and discussion

Aphis craccivora, infestations on faba bean cultivars

In the two successive seasons of 2004/05 and 2005/06, winged aphids began to appear on faba bean plants in low numbers in December. The weekly means were 0.6, 1.1, 0.5 and 1.8 aphids / plant for cultivars Misr 1, Misr 2, Giza 40 and Giza 429, respectively. Infestation rates began to increase gradually, but with no visible differences between faba bean cultivars, in the last week of January, being 20.4, 15.4, 21.4 and 21.3 aphids / plant for Misr 1, Misr 2, Giza 40 and Giza 429, respectively. Differences between cultivars started to appear in the first week of February (30.1, 27.3, 34.2 and 40.5 aphids / plant for Misr 1, Misr 2, Giza 40 and Giza 429, respectively), and reached their maximum during the period from the third week of February (47.1, 51.7, 75.4 and 80.2 aphids/plant for Misr 1, Misr 2, Giza 40 and Giza 429, respectively) until the first week of March (50.5, 54.8, 69 and 76.3 aphids / plant for Misr 1, Misr 2, Giza 40 and Giza 429, respectively). Then, infestations began to decrease from the second week of March (10.3, 9.1, 17.4 and 15.2 aphids / plant for Misr 1, Misr 2, Giza 40 and Giza 429, respectively) until the end of the season.

Liriomyza trifolii, infestations on faba bean cultivars

During the two successive seasons of 2004/05 and 2005/06, infestation by *L. trifolii* began in December, with a low percentages of plants infested (1.7, 1.6, 1.6 and 1.6% for Misr 1, Misr 2, Giza 40 and Giza 429, respectively). Infestations then increased slightly but did not differ between cultivars. Higher infestation rates were found in the first week of March (25.4, 17.8, 27.2 and 19.6% for Misr 1, Misr 2, Giza 40 and Giza 429, respectively). This level was maintained until the end of the experiment on 2nd April. The differences between cultivars may be due to preferences expressed during host selection (Powell and Hardie, 2000) or to the differing responses of cultivars to weather conditions (Mohammad and Mahmoud, 1988). The present results are similar to the findings of EL-Serwy (1993).

Parasitism of *A. craccivora*

Parasitoid adults recovered from *A. craccivora* were identified as *Lysiphlebus fabarum* March., *Aphidius matricariae* Hali. and *Trioxys sp.* (Braconidae). These species of parasitoid were also found by Volkl and Stechmann (1998).

Parasitism of *L. trifolii*

Three species of parasitoids, *Diglyphus isaea* Walker, *Pnigalio* sp. (Eulophidae) and *Opius* sp. (Braconidae), were associated with *L. trifolii*. These species of parasitoid were also found by EL-Serwy (1993). February and March seem to be the most important period for infestation by the most important insect pests attacking faba bean. Peak levels of parasitism of aphids and leafminers occurred during the first week of February until the third week of March, reaching their maxima at the end of February. Therefore, the application of biological control methods, especially parasitoids, should be conducted in this period.

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Laboratory investigation of the biology of *Bactericera tremblayi* Wag. (Homoptera: Triozidae) a new pest in onion fields of Iran

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Abstract

Psyllids are a small group of insects, the adults and nymphs of which feed on the host plant. Apart from direct feeding damage, they can transmit plant diseases, especially plant viruses. The population of *Bactericera tremblayi* recently increased to high densities in onion fields in East Azarbaijan province in Iran, and the pest has become widespread. This is the first study of the biology of the pest in Iran, and probably in the world, since reports on the biology of this psyllid are scarce. The experimental insects were maintained inside a growth-chamber at 21±3°C, 60±10% R.H. and under a 14:10 (L: D) light regime. The life span of adult male and female psyllids was 33.63±9.44 and 39.94±10.57 days, respectively. The pre-oviposition period was 3.75±0.57 days. The total number of eggs laid by a female was 625.45±215.60. Egg incubation took 7.44±0.61 days and a mean of 90.28% eggs hatched. The nymphs passed through five instars before reaching the adult stage and the development time for the nymphal stage was 17.71±2.42 days. The sex ratio was estimated as 1:1.

Introduction

Onion (*Allium cepa* L.) is one of the most important crops in Iran, especially in East Azarbaijan province. About 10,000 ha of onion are cultivated in the province, using an Iranian native variety (Azarshahr), with an average 40 t yield per ha. Due to the application of chemical pesticides against onion thrips, the most important and dominant pest in onion fields, the natural balance of insect fauna has changed. As a result, the population of onion psyllid (*Bactericera tremblayi*) has increased. Based on observations made during this investigation, the largest infestations of psyllids have been observed in onion fields in the Tabriz region. Before undertaking studies to develop an IPM (Integrated Pest Management) Programme for this pest, it was necessary to study its morphology and bioecology. Information about the biology of this psyllid is scarce.

This study is the first such investigation in Iran, and probably in the world. Studies on its taxonomy were reported by Klimaszewski & Lodos (1979), Annunziata *et al.* (1980), Hodkinson (1981) and Burckhardt & Lauterer (1997). This pest was first reported in Iran by Hassan Zadeh (1996), as part of the insect fauna of onion fields of East Azarbaijan province, and was evaluated subsequently by the authors of this paper. The identity of *B. tremblayi* was confirmed by Burckhardt.

Table 1 Effects of some novel pesticides on lepidopteran pests of vegetables (mean for 2006 and 2007, and three applications/season).

Chemicals	Dose g a.i. /ha	Mean infestation (percent) and yield (q/ha)									
		Cabbage *		Tomato*		Chilli*		Brinjal		Okra	
		Infested by DBM (%)	Yield	Fruit borer infestation (%)	Yield	Pod borer infestation (%)	Yield	Shoot & fruit borer infestation (%)	Yield	Shoot & fruit borer infestation (%)	Yield
Flubendiamide 20 WDG	50	1.25 (6.29)	165.5	2.70 (9.46)	190	1.75 (7.60)	17.56	7.25* (15.62)	168.70	5.30* (13.31)	118.40
Pyridalyl 10 EC	50	1.60 (7.27)	156	2.85 (9.63)	187	2.00 (8.13)	16.84	9.85* (18.30)	156.40	7.5* (15.89)	109.50
Spinosad 45 S.C.	50	1.33 (6.55)	164	2.05 (8.33)	211	1.70 (7.49)	17.50	8.15* (16.59)	159.40	6.10* (14.30)	112.50
Emamectin benzoate 5 SG	15	3.24 (10.34)	147	3.70 (11.09)	162	2.85 (9.71)	15.26	15.20* (22.95)	139.20	10.10* (18.53)	96.00
Bacillus thuringiensis Kurstaki	1000 ml/ha	4.50 (12.25)	131	5.75 (13.81)	141	4.20 (11.83)	14.25	26.15 (30.75)	109.40	17.10 (24.43)	71.20
Novaluron 10 EC	50	1.85 (7.71)	151	3.00 (9.97)	178	1.65 (7.38)	18.00	12.60* (20.79)	143.60	9.76* (18.20)	96.50
Methoxyfenozide 24 SC	200	3.4 (10.63)	133	3.85 (11.24)	164	4.10 (11.68)	15.05	19.25 (26.03)	126.00	16.25* (23.77)	74.30
Indoxacarb 14.5 EC	50	2.60 (9.28)	147	3.15 (10.14)	179	2.15 (8.43)	16.60	10.20* (18.63)	149.60	8.20* (16.64)	99.60
Chlorpyrifos + Cypermethrin 55 EC	500	4.80 (12.66)	118	8.15 (16.54)	132	5.75 (13.88)	13.70	14.60* (22.46)	142.30	10.25* (18.68)	94.50
Untreated	-	19.60 (26.28)	72.50	21.80 (27.83)	79	16.50 (23.97)	7.08	34.50 (35.97)	83.50	28.75 (32.42)	59.60
C.D. at 5%		7.25	30.50	8.70	34.60	6.25	7.15	11.45	27.80	9.72	17.70

Figures in parentheses are transformed values; * significant at 5% level.

Materials and methods

Plants and insect culture

Onion seeds were sown in 15 cm diameter plastic pots at a depth of 2 cm and thinned to one plant per pot after germination. The soil was a mixture of field soil, compost and manure obtained from the Agricultural Research Center of East Azarbaijan. Psyllid nymphs were taken from infested onion fields and maintained under controlled conditions (see below) in the laboratory to provide a stock culture.

Plant infestation

The experimental insects were maintained inside a growth-chamber at 21±3°C, 60±10% R.H. and under a 14:10 (L: D) light regime. For the main experiments, one adult male and one adult female were kept together in a glass jar and the female was allowed to lay eggs on the leaves of an onion plant which was planted inside the jar. The experiment used a completely randomized design with 20 replicates, using individual glass jars as experimental units. Adult life span, the pre-oviposition period, total number of eggs, egg incubation time, percentage egg hatch, number of nymphal instars, nymphal development time and sex ratio were evaluated.

Results and discussion

The life span of adult male and female psyllids was 33.63±9.44 and 39.94±10.57 days, respectively. The pre-oviposition period was 3.75±0.57 days. The total number of eggs laid by a female was 625.45±215.60. Egg incubation took 7.44±0.61 days and a mean of 90.28 % eggs hatched. The nymphs passed through five instars before reaching the adult stage and the development time for the nymphal stage was 17.71±2.42 days. The sex ratio was estimated as 1:1. The data obtained in this study clarify many aspects of the biology of this pest although, due to the scarcity of similar studies, no comparisons can be made with previous studies either in Iran or in other parts of the world. Clearly these results will be invaluable for future studies, particularly in the context of the development of IPM strategies which the authors will conduct in the future.

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